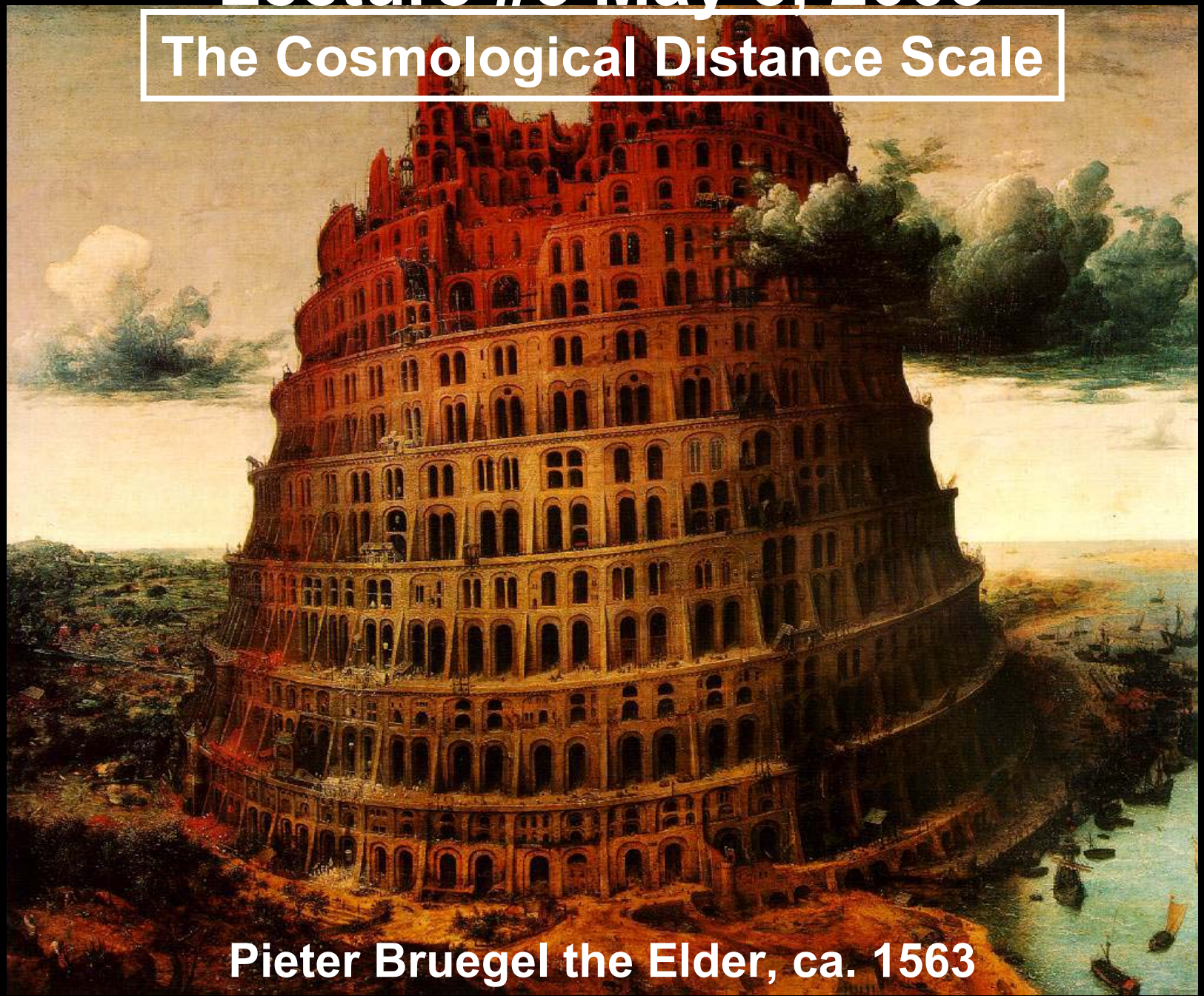
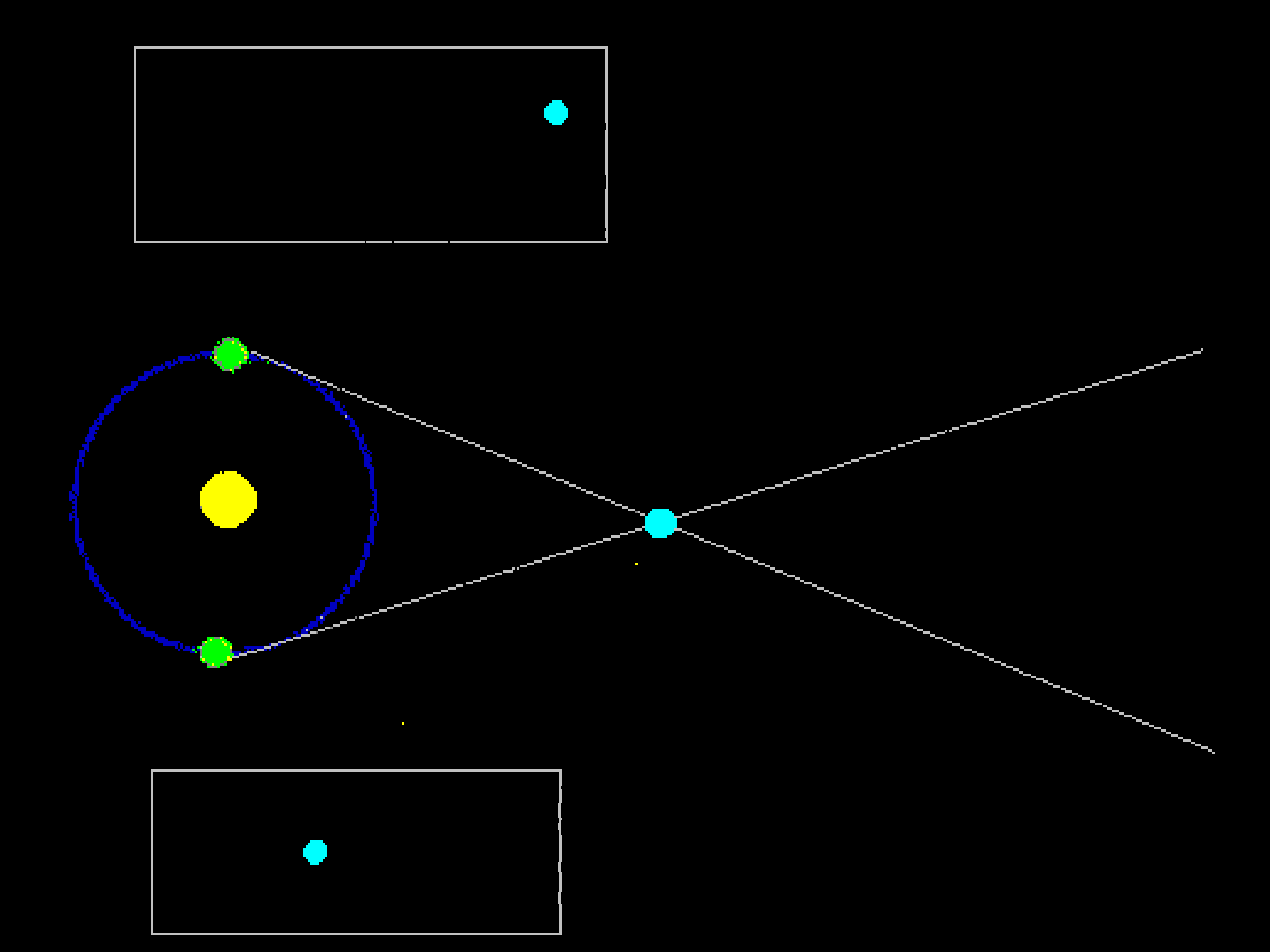
Lecture #5 May 3, 2003

The Cosmological Distance Scale



Pieter Bruegel the Elder, ca. 1563

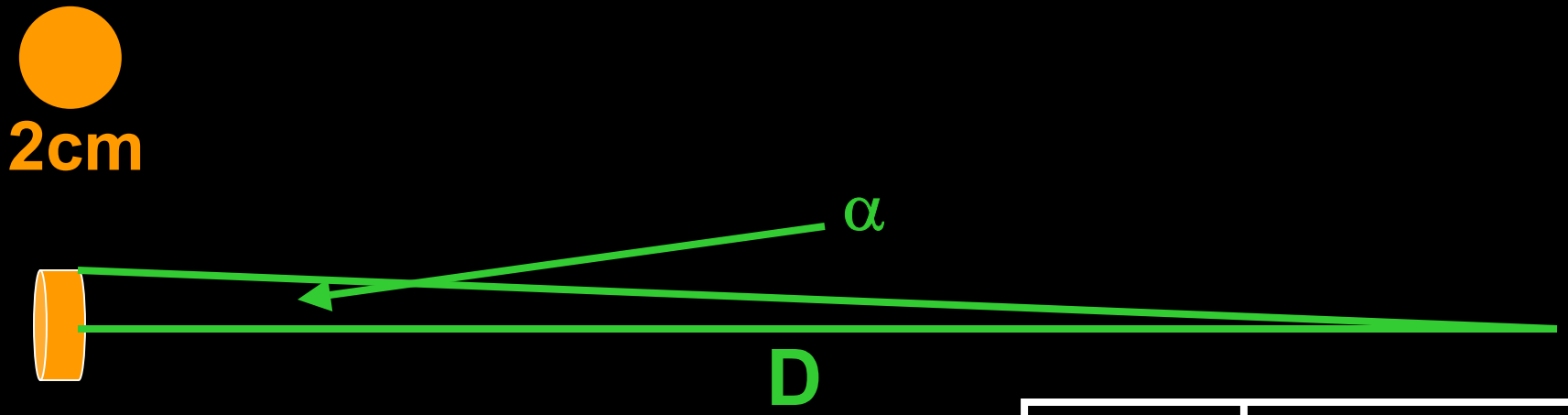
The Cosmological Distance Scale



$$\frac{D}{pc} = \frac{\text{measured in seconds of arc}}{\text{annual stellar parallax}}$$

star	parallax (”)	distance (pc)
α Centauri	0.75	1.3
Barnard’s star	0.5	2.0
Sirius	0.4	2.5
Altair	0.2	5.0

Let's think for a second of arc



$$\alpha = \frac{1\text{ cm}}{D}\ \text{radians}$$

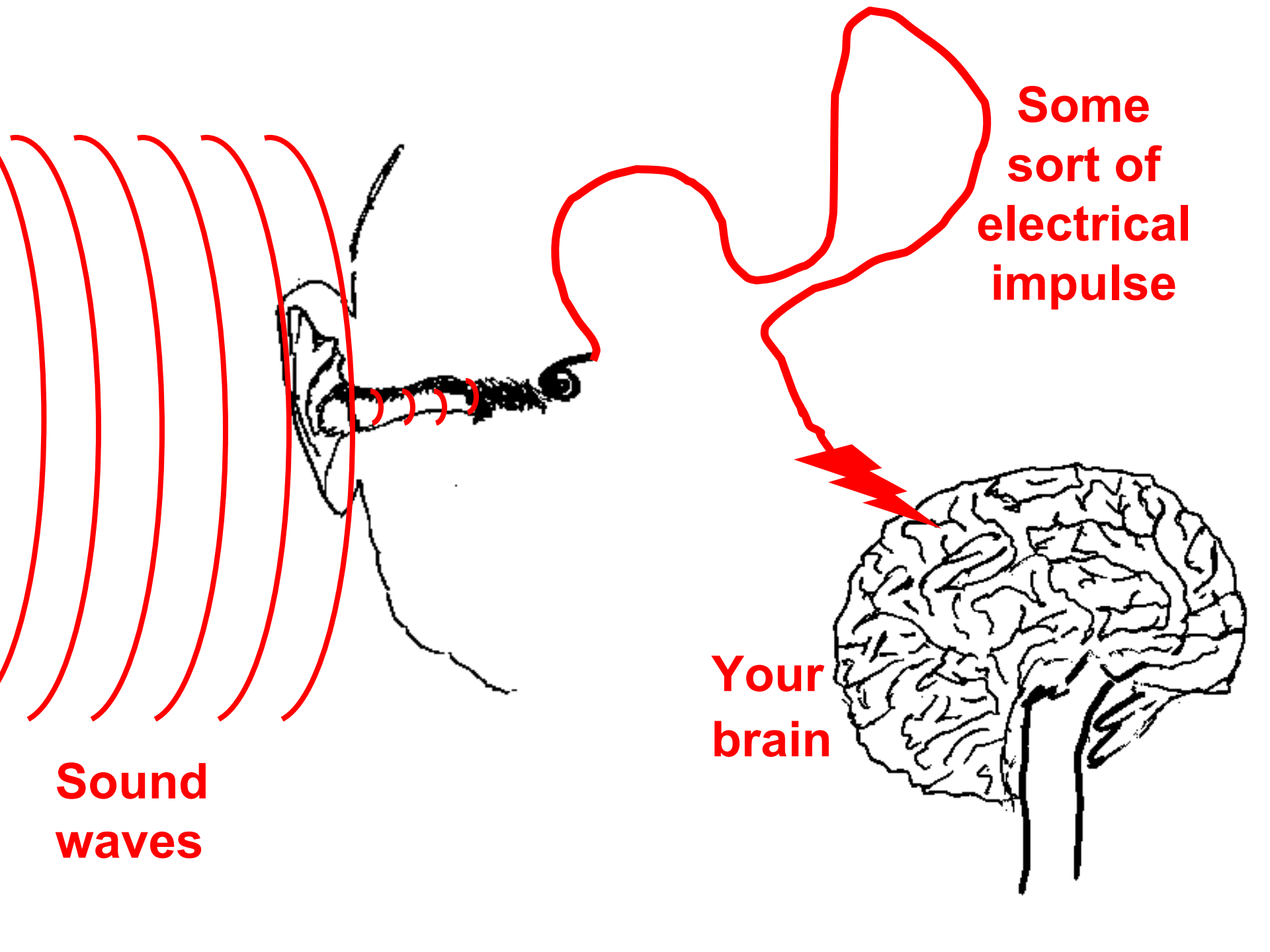
$$\alpha = \frac{200{,}000\text{ cm}}{D}\ \text{seconds}$$

$$\alpha = \frac{2\text{ km}}{D}\ \text{seconds}$$

α	D
4"	½ km
2"	1 km
1"	2 km
0.1"	20 km
0.01"	200 km
0"	infinity


Run 94 Col 3 Field 387

They have different apparent brightness
They have different colors
They move
They change in brightness


Some sort of electrical impulse
Your brain
Sound waves

$I_{THRESHOLD}$ = energy per second in ear at threshold of hearing

I_{PAIN} = energy per second in ear at threshold of pain

$I_{PAIN} / I_{THRESHOLD}$ = 10^{12} !!!

1 – 100 (10^2)

100 – 1,000 (10^3)

1,000 – 1,000,000 (10^6)

1,000,000 – 1,000,000,000 (10^9)

1,000,000,000 – 1,000,000,000,000 (10^{12})

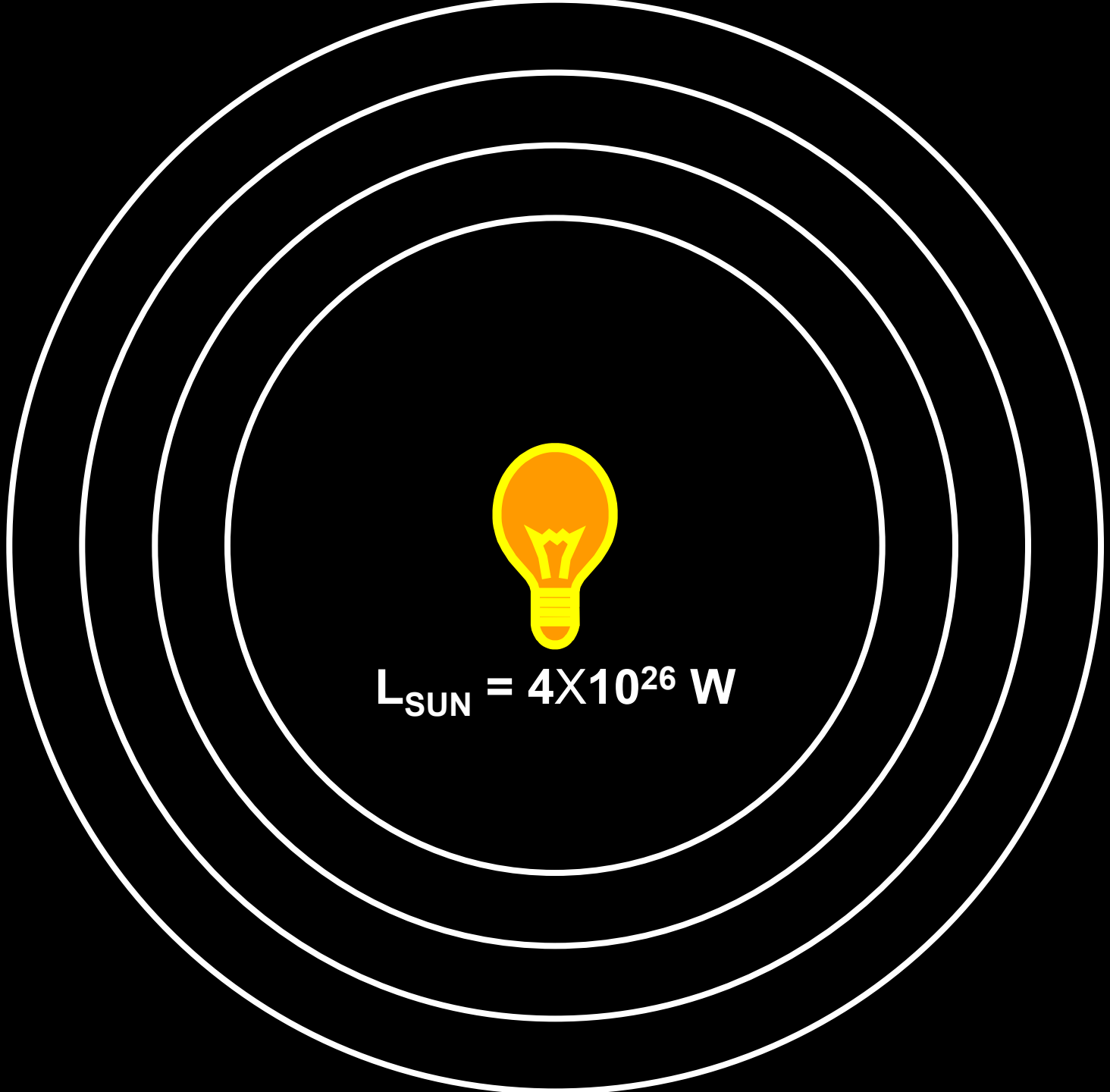
Intensity: energy per time per area

$$I = \frac{\text{Energy}}{\text{Time}\ \ \text{Area}}$$

$\frac{\text{Energy}}{\text{Time}}$ can be measured in watts

Area can be measured in cm^2

Intensity in watts per cm^2


$L_{SUN} = 4X10^{26}$ W

Intensity: energy per time per area

$$I = \frac{\text{watts}}{\text{cm}^2}$$

Power (watts) property of source

Intensity depends on power and distance between source and detector

$$\text{Intensity} = \frac{\text{power}}{4\pi R^2}$$

LET THERE BE LIGHT!

Greeks classified stars into 6 classes, or magnitudes

Brightest stars were 1st magnitude
Dimmest stars were 6th magnitude

Eyes, like ears, are logarithmetic detectors.

Intensity of brightest stars = 100 X dimmest.

Some Magnitudes

Sun	m = – 26.8
Venus	m = – 4
Sirius	m = – 1.5
Naked eye limit	m = 6
Binoculars	m = 10
Pluto	m = 15
Large telescope (visual)	m = 20
Large telescope (photograph/ccd)	m = 25

Our Sun ain't the brightest bulb in the box!

$$L_{SIRIUS} = 25 \times L_{SUN}$$

$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

For stars we know distance to via parallax:

Measure Distance (R)
Measure Intensity
→ Know Luminosity

$$\frac{d}{pc} = \frac{''}{parallax}$$

star	parallax (”)	distance (pc)	apparent magnitude	luminosity (solar)
α Centauri	0.75	1.3	0	1.5
Barnard’s star	0.5	2.0	9.5	0.0005
Sirius	0.4	2.5	-1.5	25
Altair	0.2	5.0	0.8	10
Canopus	0.003	330	- 0.7	200,000
Arcturus	0.1	10	0	90
Betelgeuse	0.01	100	0.5	14,000

$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

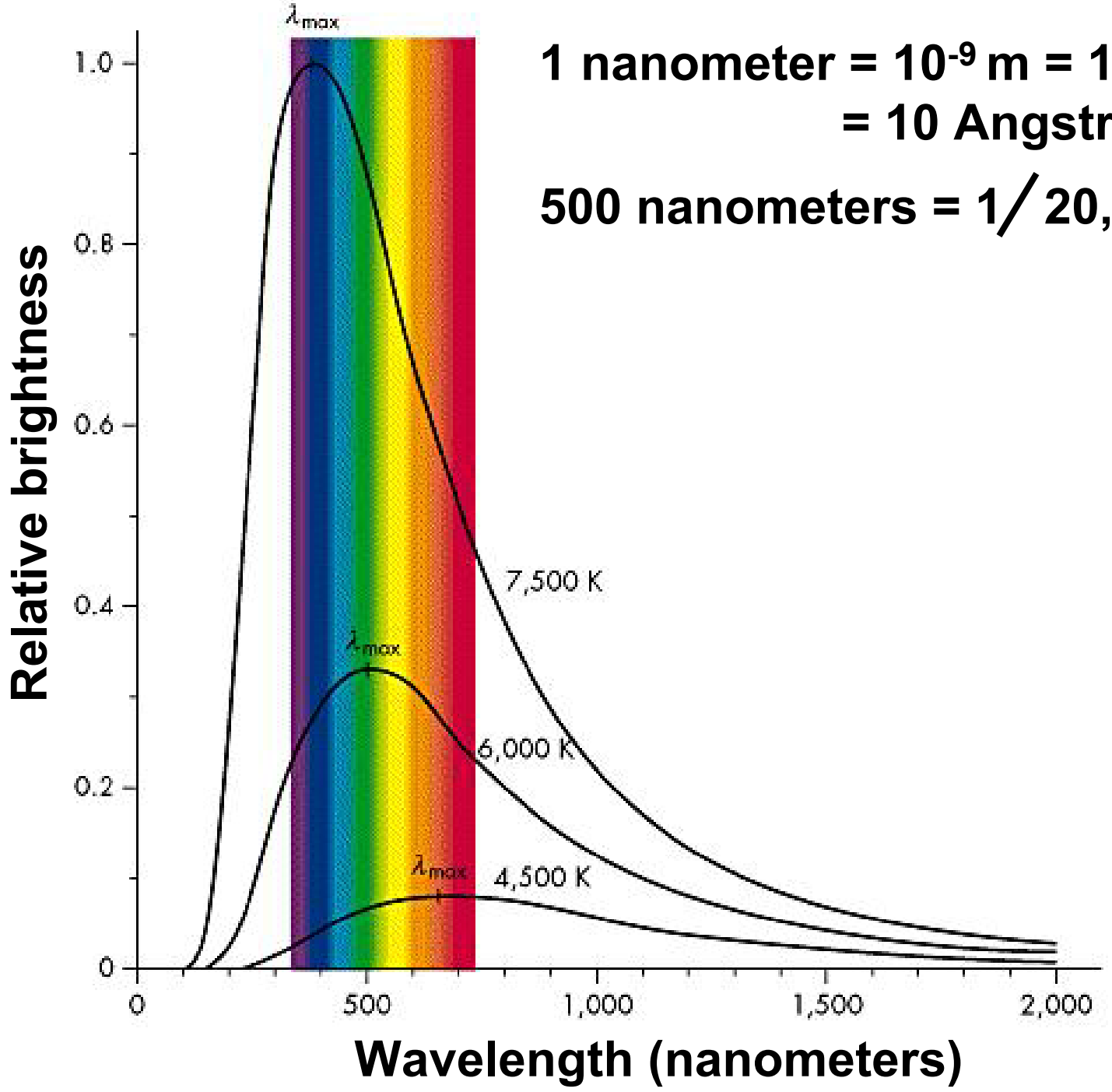
For stars we know Luminosity:

Measure Luminosity
Measure Intensity → **Know Distance**

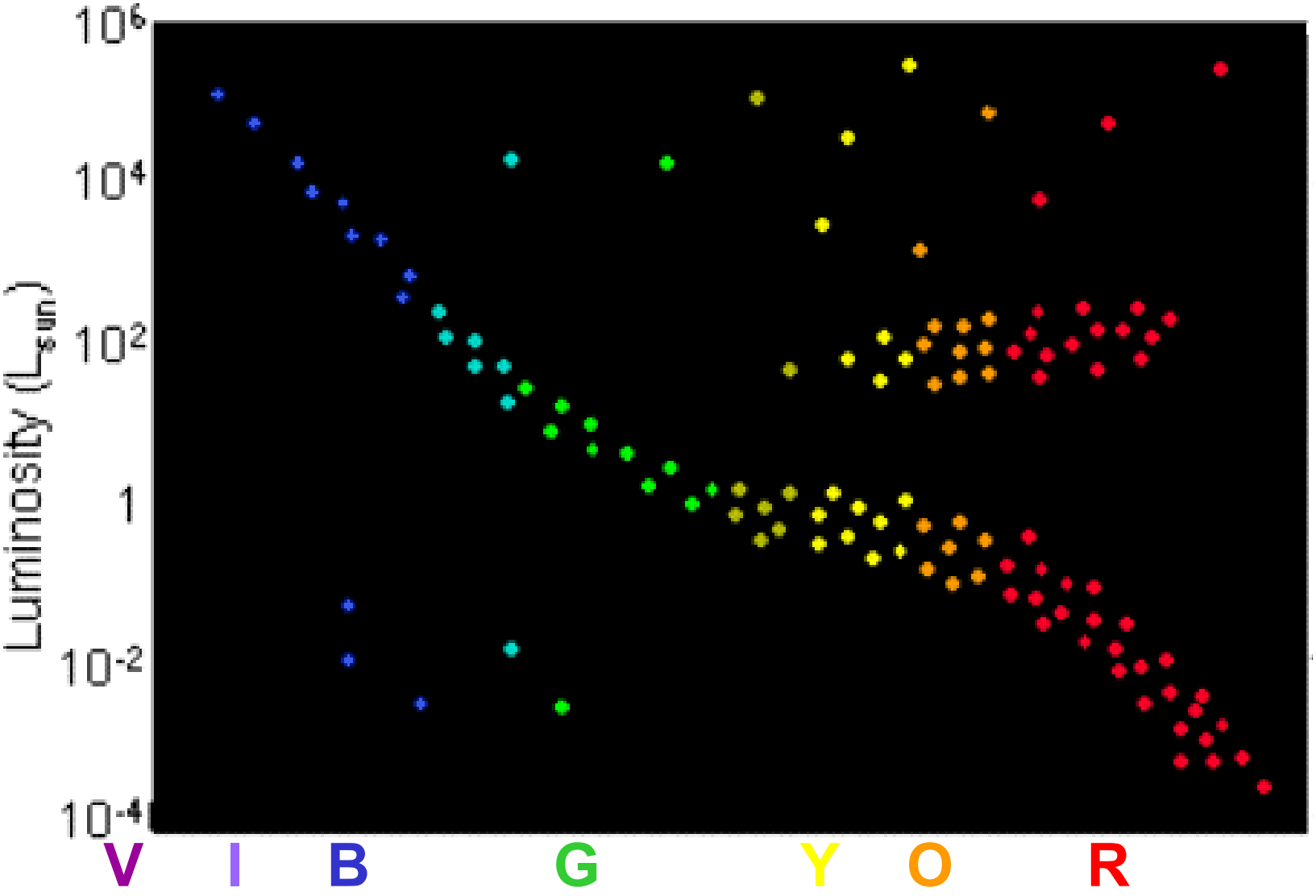
They have different apparent brightness
They have different colors
They move
They change in brightness

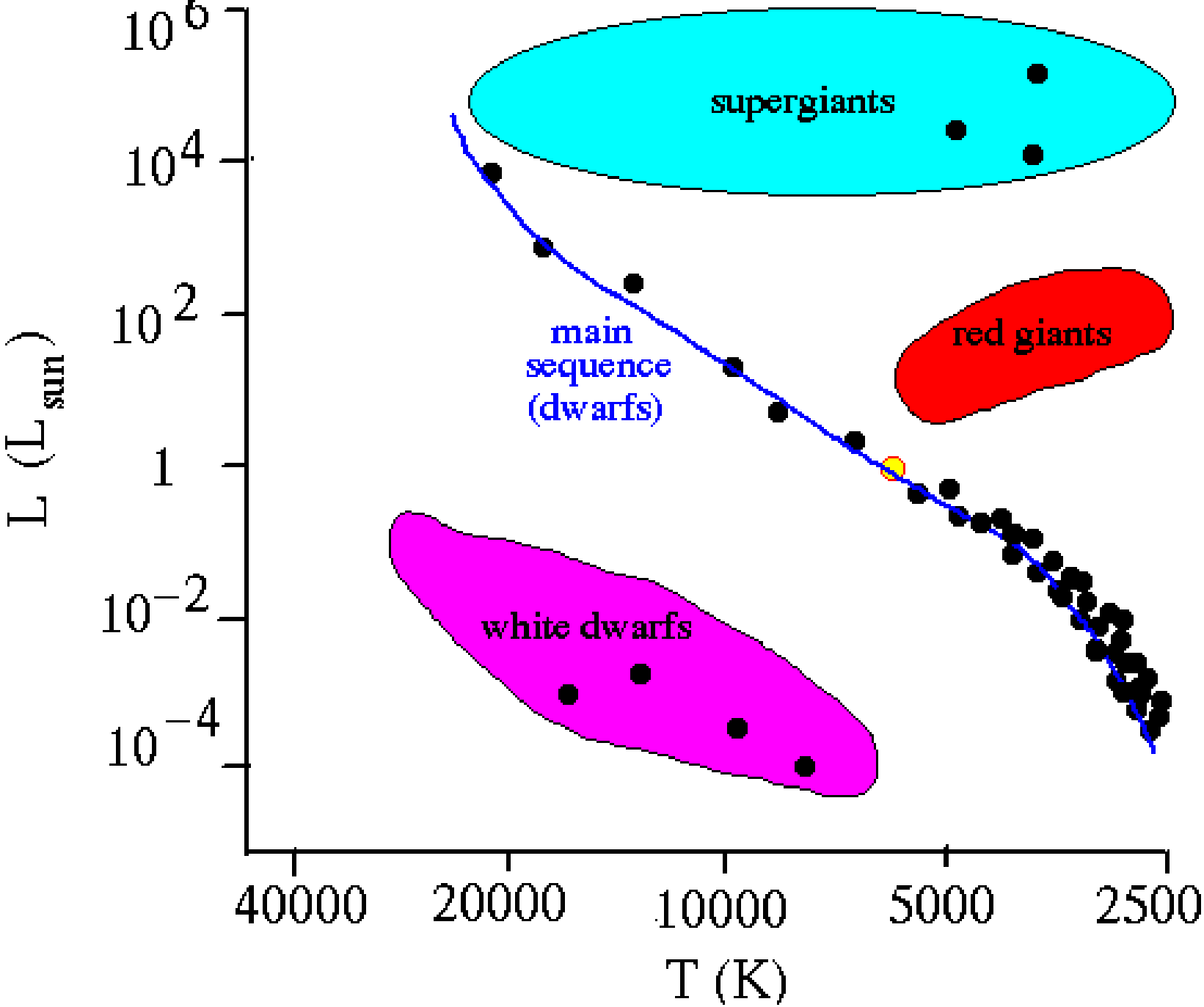
COLORS OF THE RAINBOW:

R O Y – G – B I V

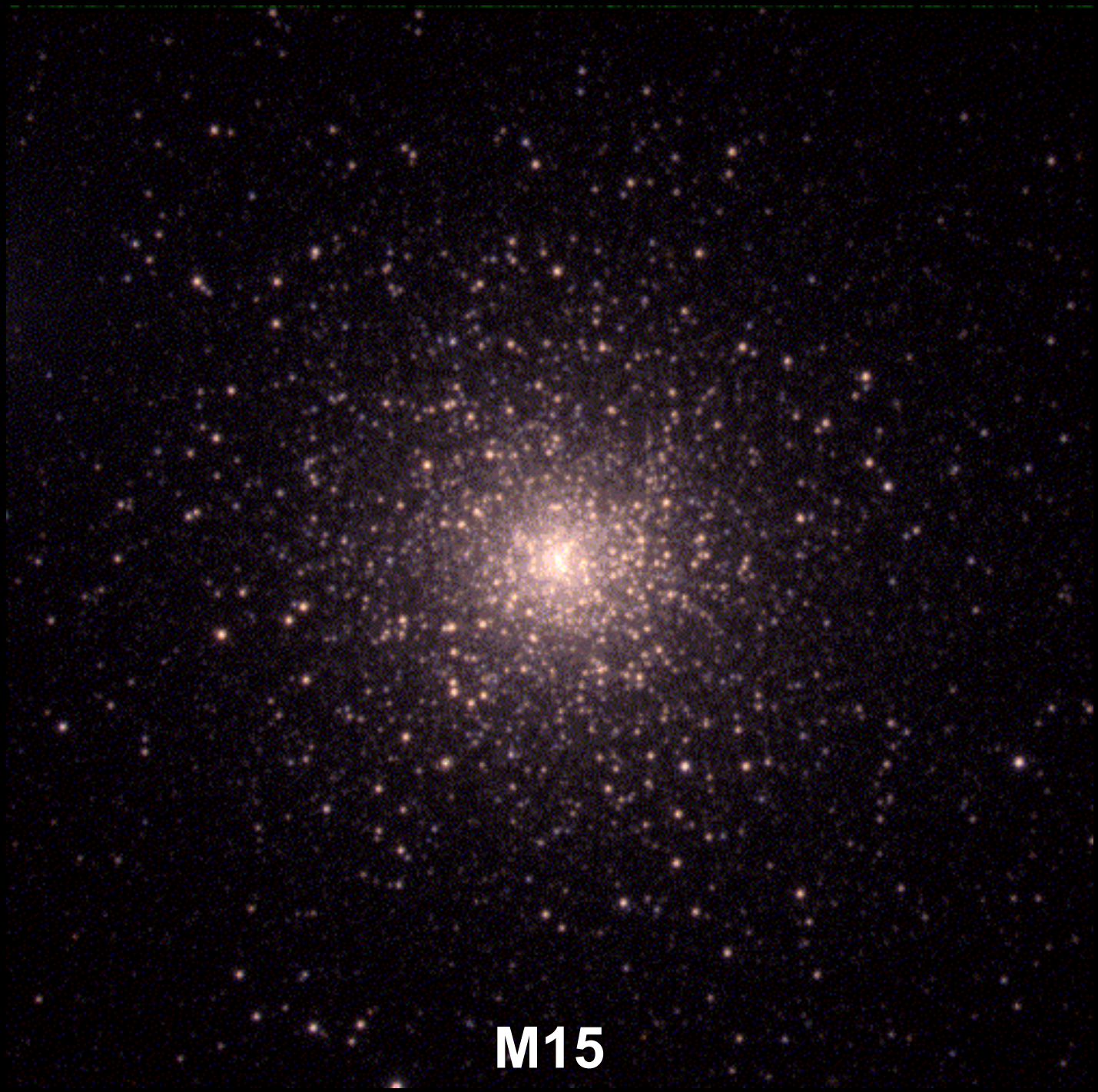

1 nanometer = 10-9 m = 10-7 cm
= 10 Angstroms
500 nanometers = 1/20,000 cm
Relative brightness
1.0
0.8
0.6
0.4
0.2
0
λmax
7,500 K
λmax
6,000 K
λmax
4,500 K
0
500
1,000
1,500
2,000
Wavelength (nanometers)

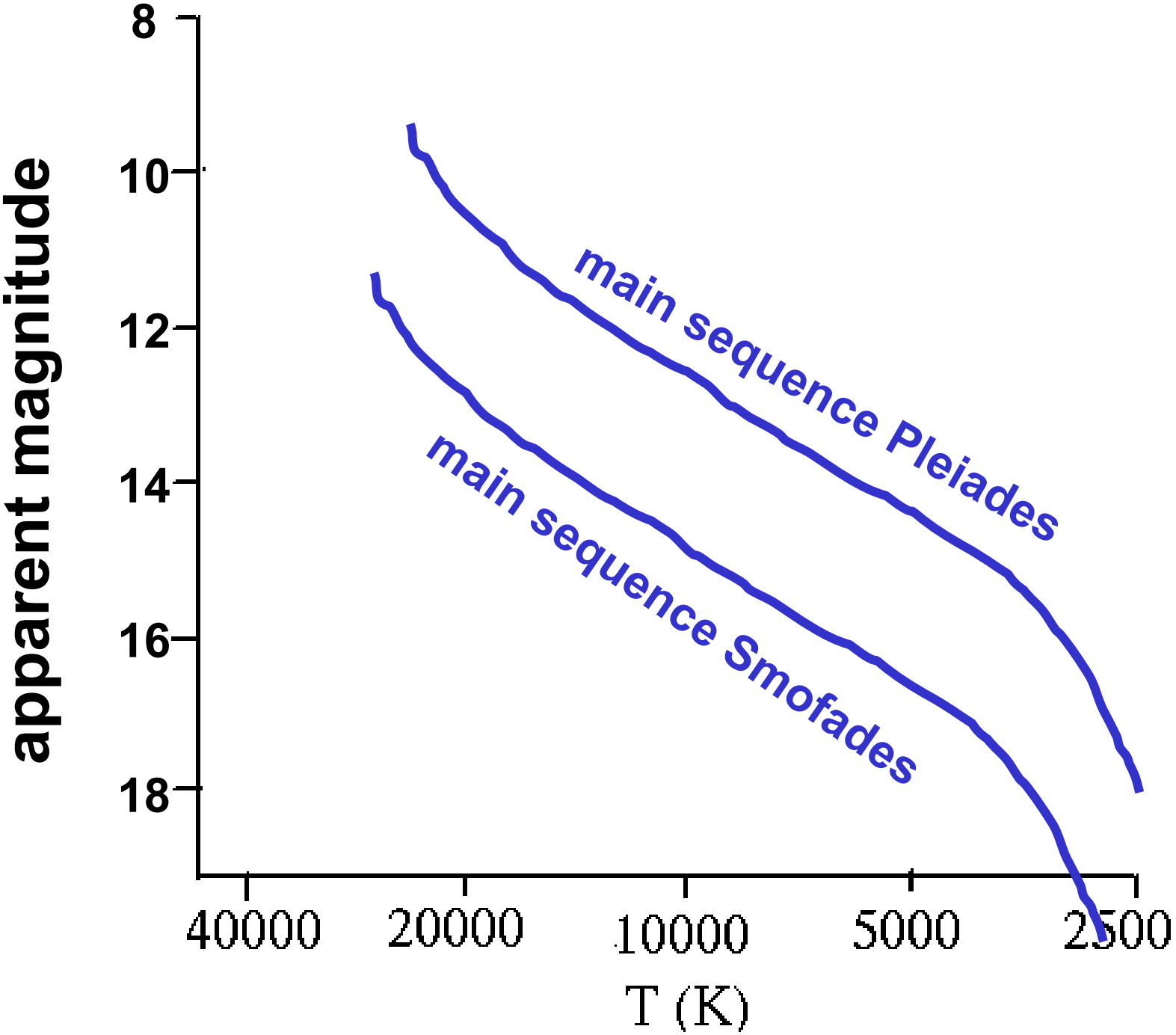
Schematic Hertzsprung-Russell Diagram



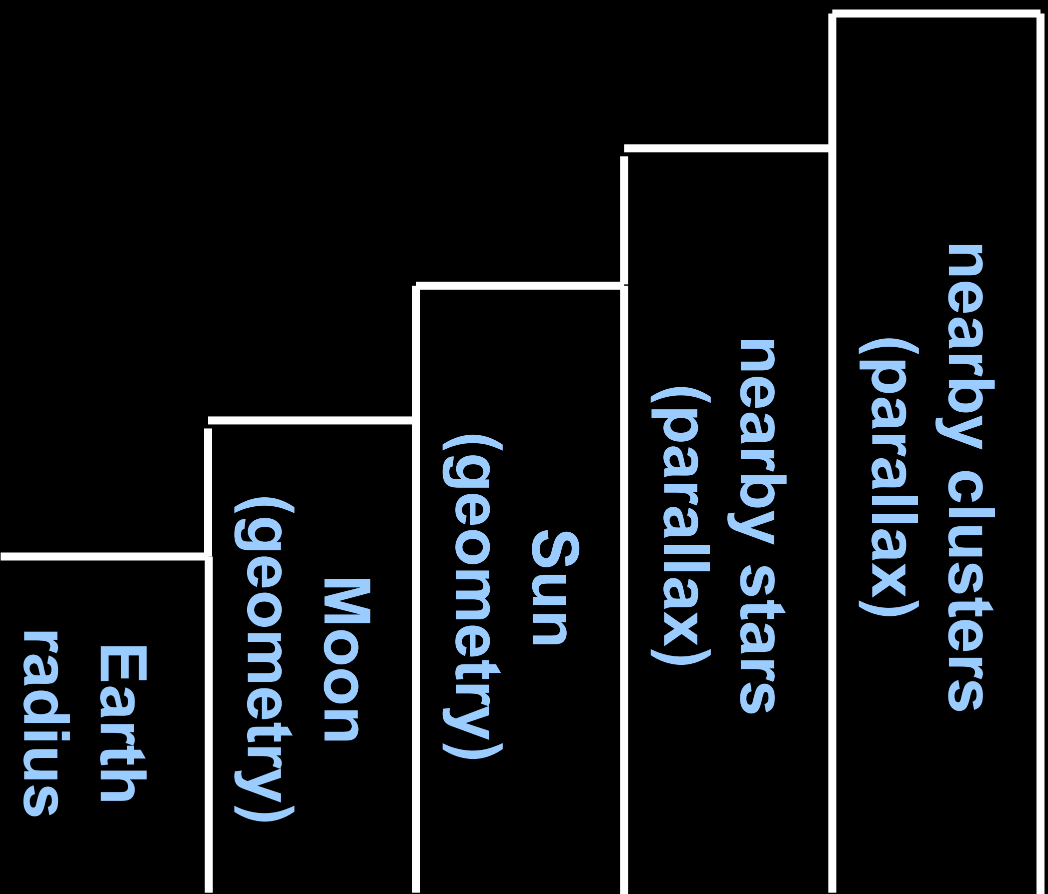

10^6
10^4
10^2
1
10^{-2}
10^{-4}
L (L_{sun})
supergiants
main sequence (dwarfs)
red giants
white dwarfs
40000
20000
10000
5000
2500
T (K)

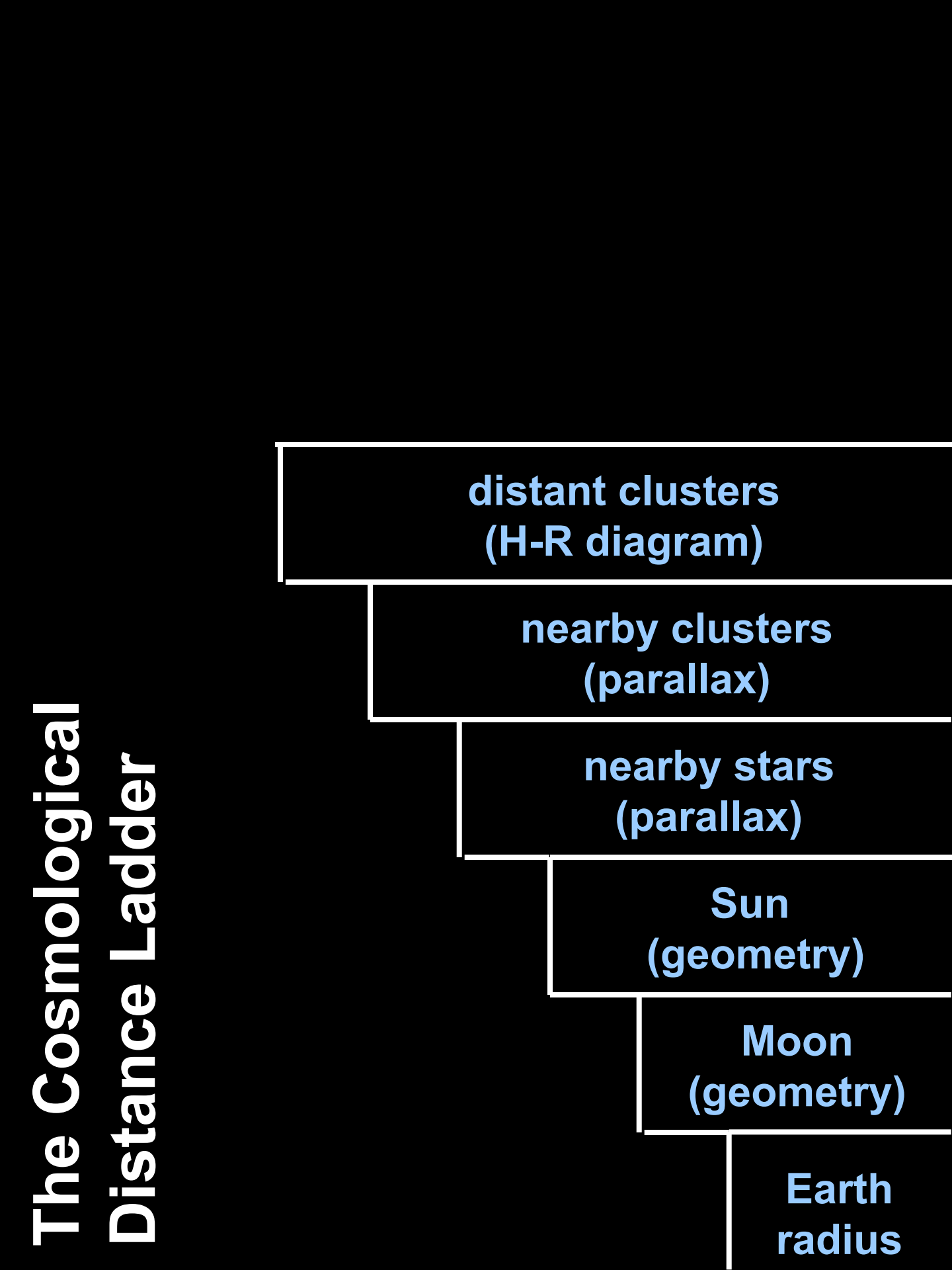

Open Cluster (The Pleiades)
130 pc distant


M15


apparent magnitude
8
10
12
14
16
18
main sequence Pleiades
main sequence Smofades
40000
20000
10000
5000
2500
T (K)

The Cosmological Distance Ladder




The Cosmological Distance Ladder
distant clusters (H-R diagram)
nearby clusters (parallax)
nearby stars (parallax)
Sun (geometry)
Moon (geometry)
Earth radius

They have different apparent brightness
They have different colors
They move
They change in brightness

• Main sequence stars are not extremely bright… we need brighter "standard candle"

$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

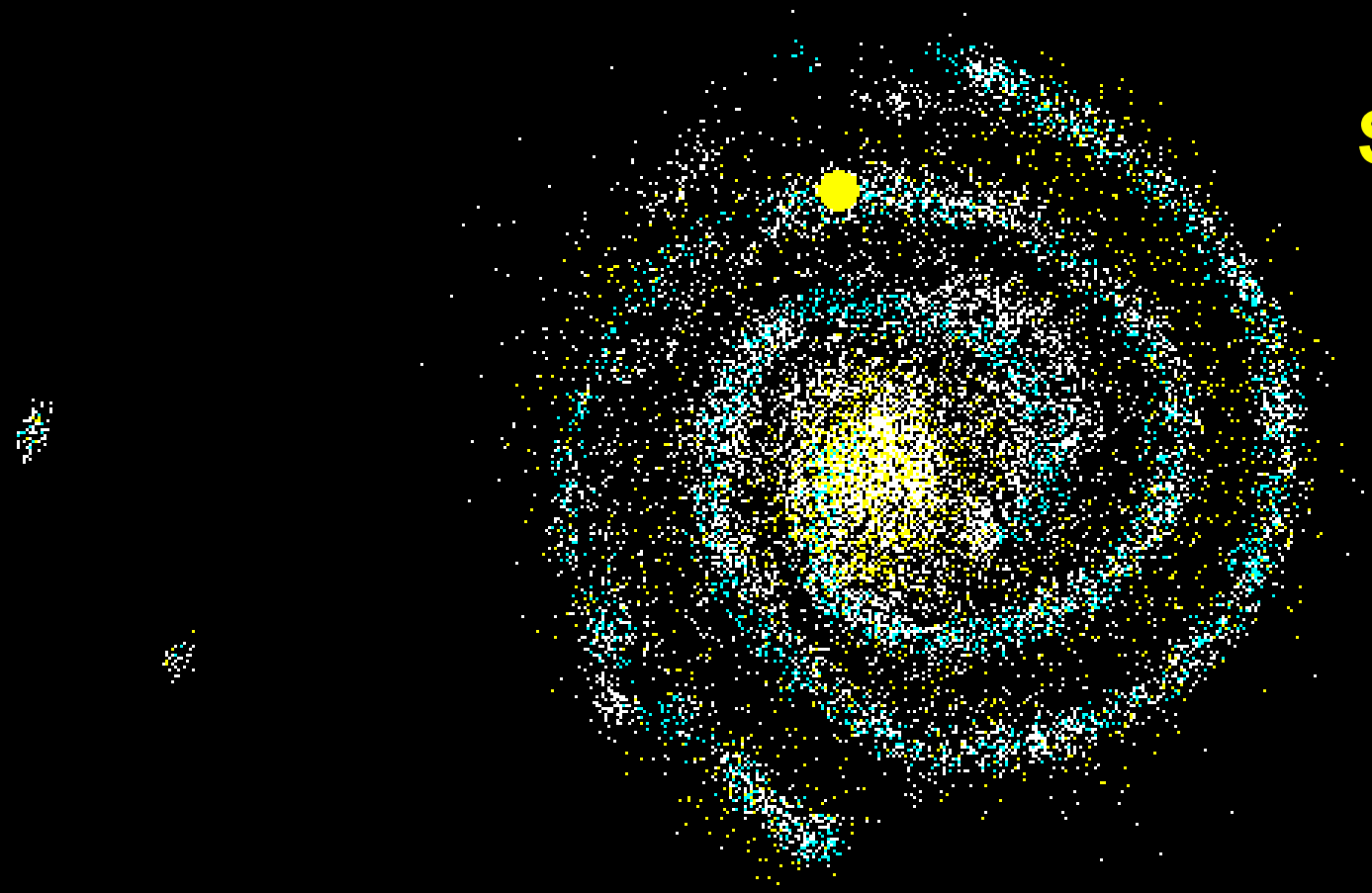
• RR Lyrae stars found in distant clusters we know the distance to via H-R fitting.

• RR Lyrae stars are identified because their light output changes regularly on a time scale of half to one day.

• They are brighter than the sun by about a factor of 100 and are standard candles. Can see farther away and use as standard candle.

Large Magellanic Cloud 100 million stars 55 kpc distant

Milky Way Galaxy



Large and Small Magellanic Clouds

- Need brighter "standard candle"

$$\text{Intensity} = \frac{\text{Luminosity}}{4\pi R^2}$$

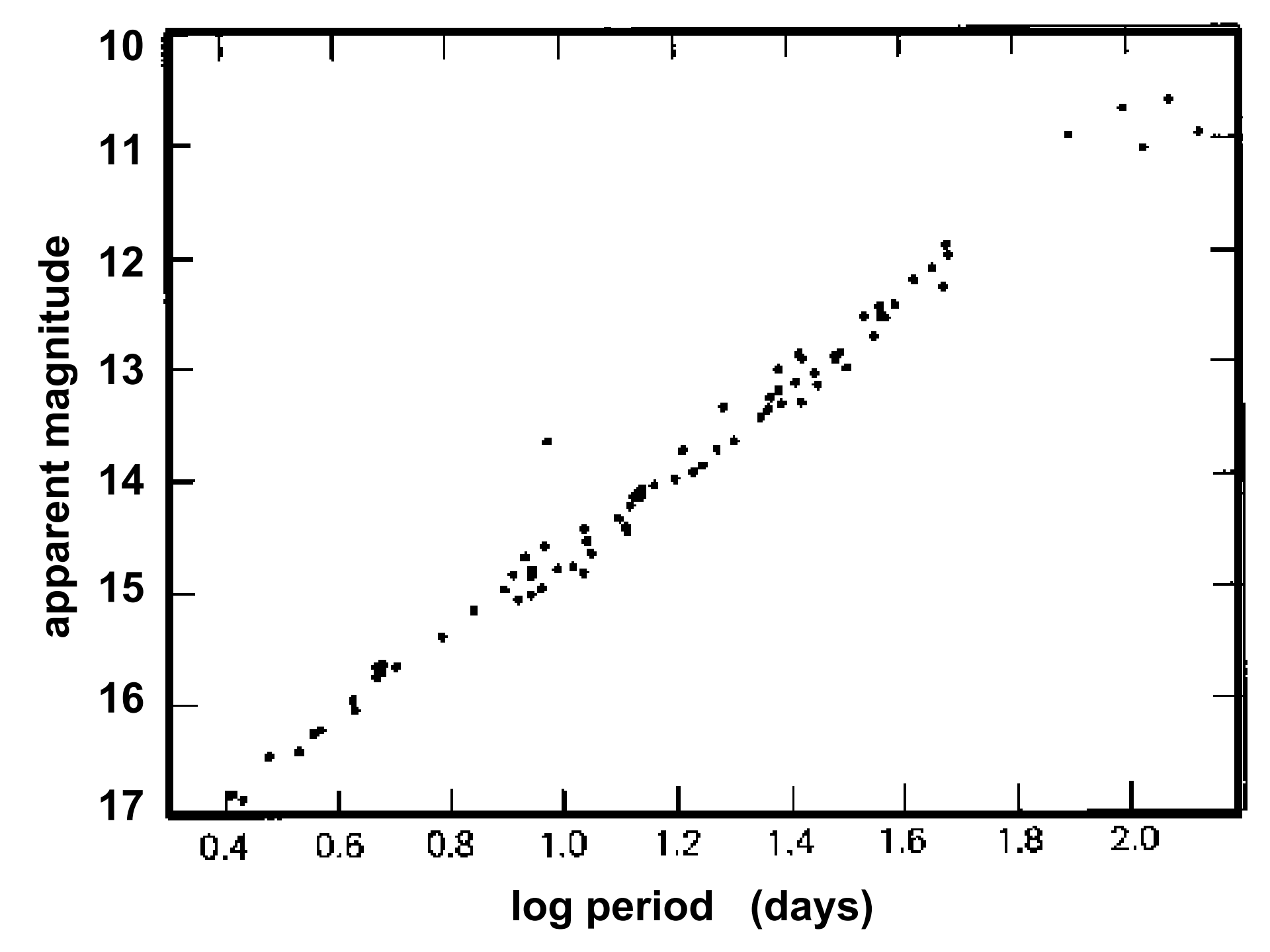
- Other variable stars are brighter: **Cepheid Stars**
  (Polaris is a Cepheid)

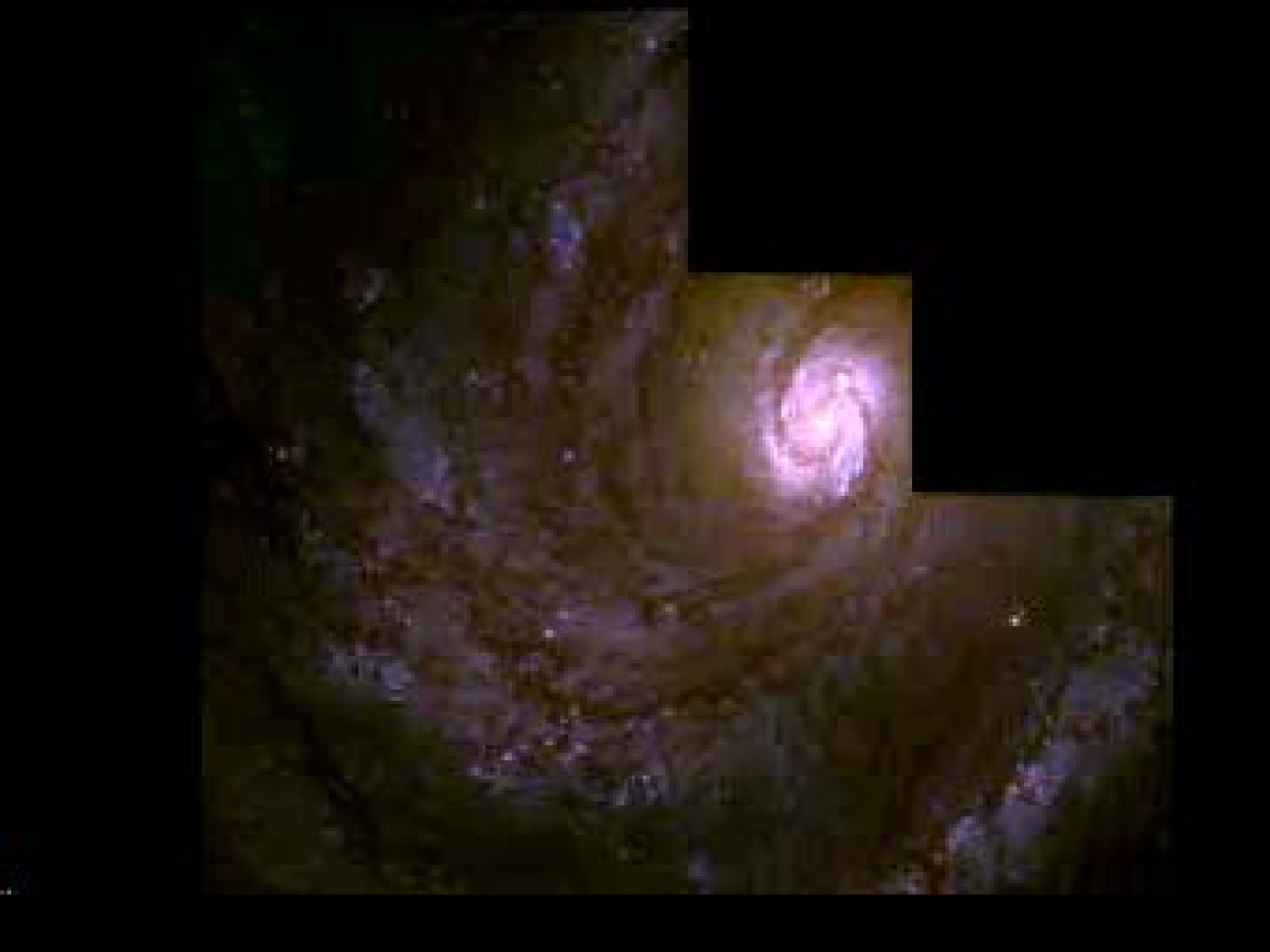
- Cepheid stars are identified because their light output changes regularly on a time scale of weeks to months. They are very rare.

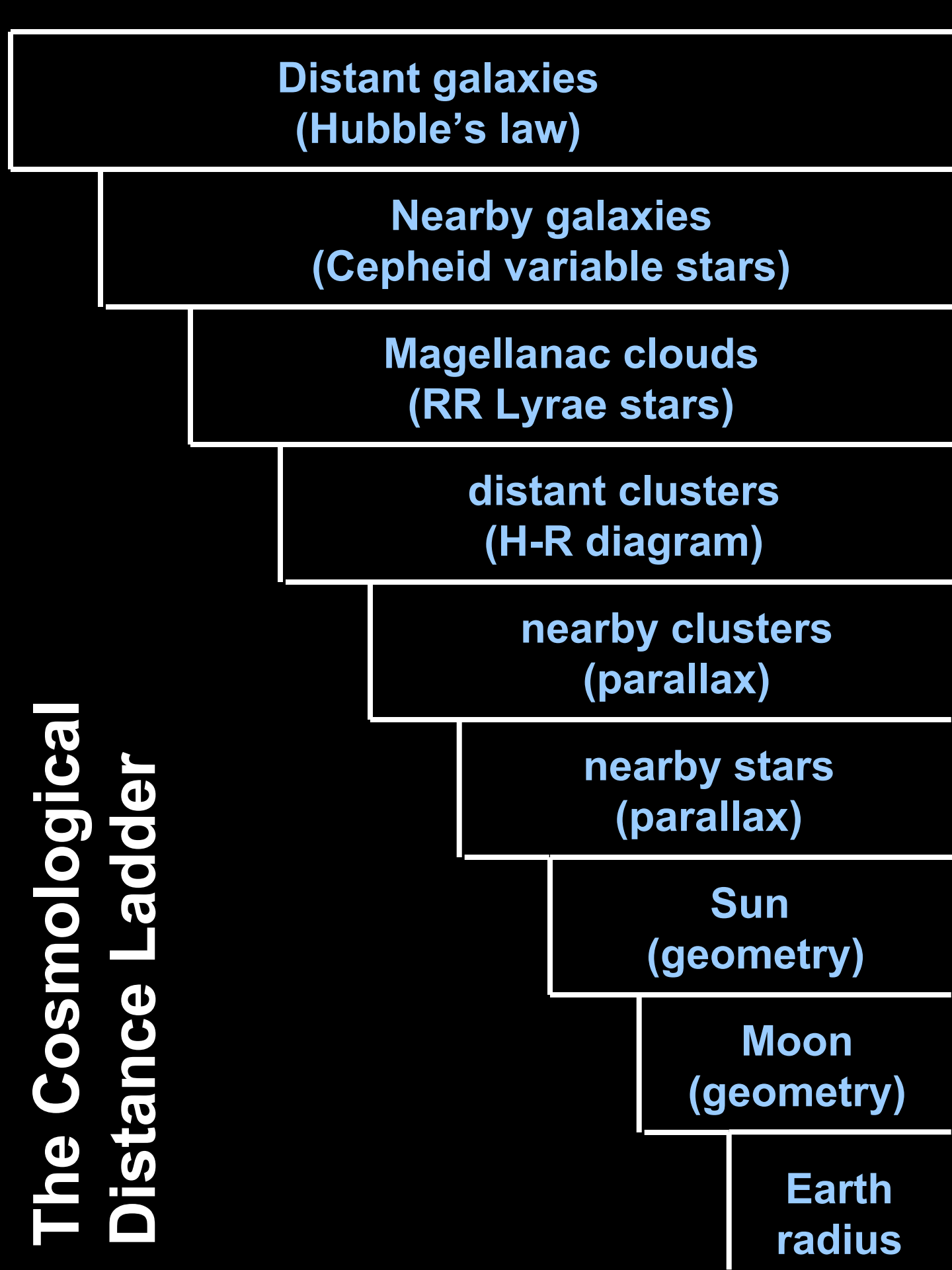
- They are brighter than the sun by about a factor of 10,000 but are <u>not</u> standard candles.

Cepheid Variable Stars

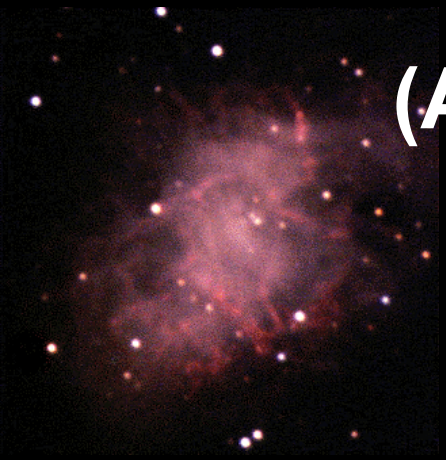
Henrietta Leavitt
1868 - 1921

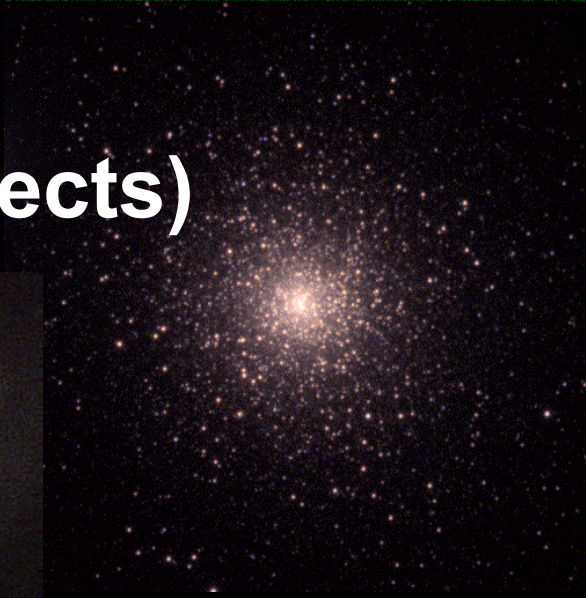

10
11
12
13
14
15
16
17
apparent magnitude
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
log period (days)



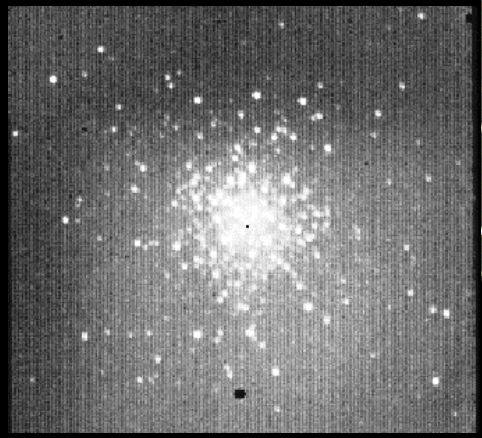

Distant galaxies
(Hubble's law)
Nearby galaxies
(Cepheid variable stars)
Magellanac clouds
(RR Lyrae stars)
distant clusters
(H-R diagram)
nearby clusters
(parallax)
nearby stars
(parallax)
Sun
(geometry)
Moon
(geometry)
Earth
radius
The Cosmological
Distance Ladder

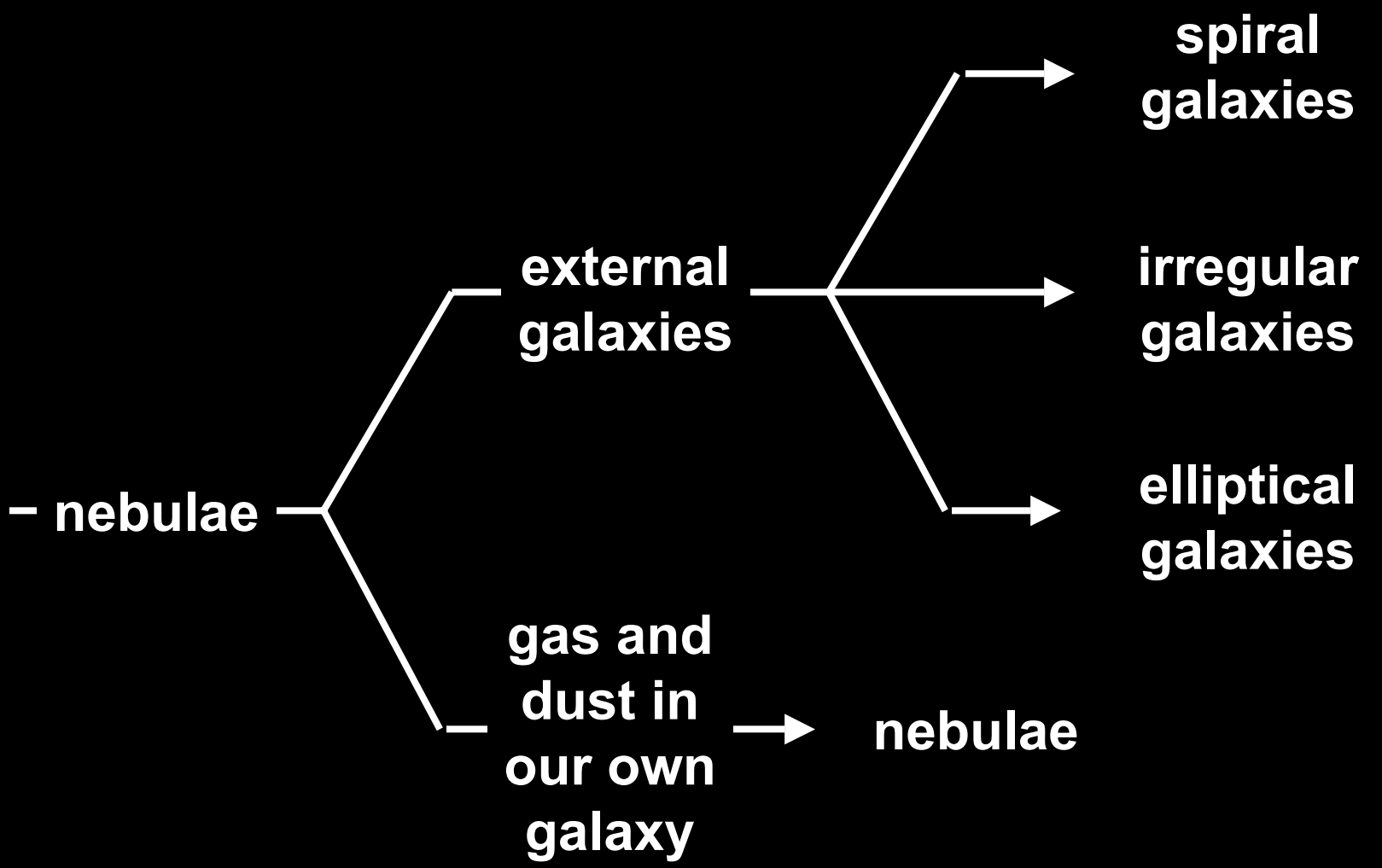
Clouds in the Sky
(A Mess of Messier Objects)

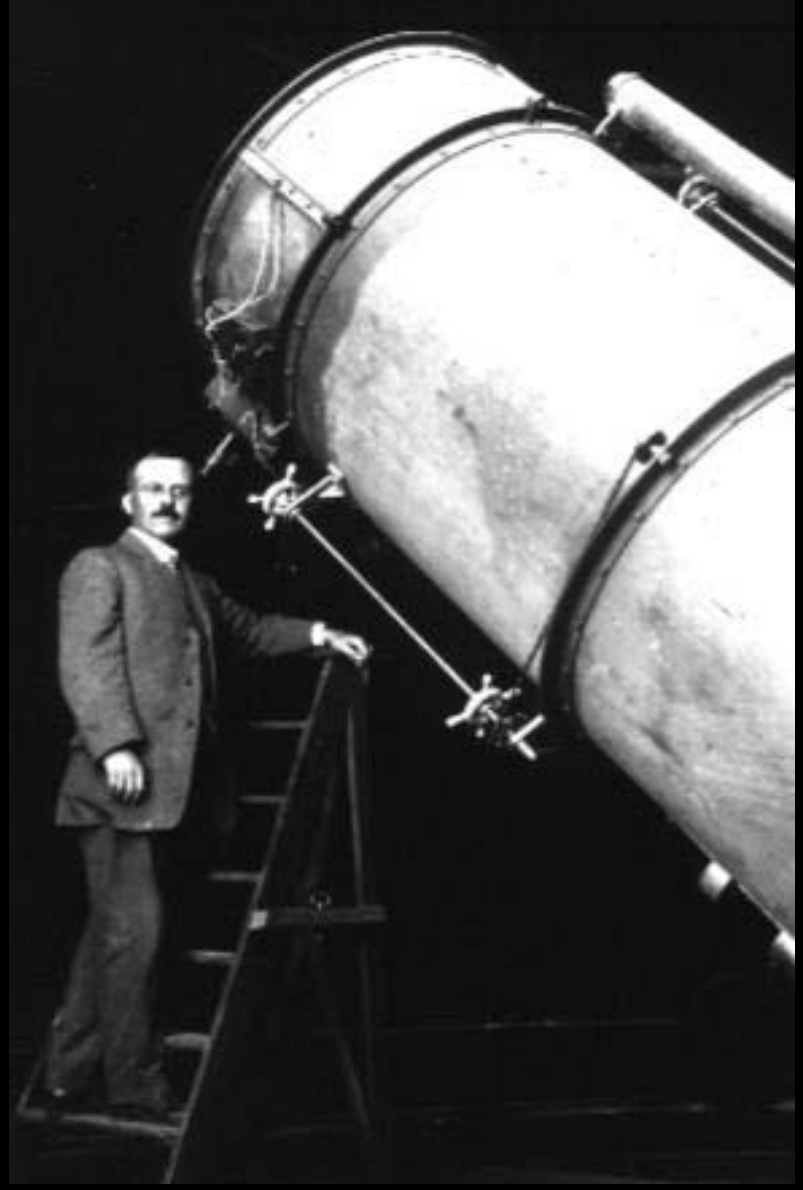







nebulae
external galaxies
spiral galaxies
irregular galaxies
elliptical galaxies
gas and dust in our own galaxy
nebulae



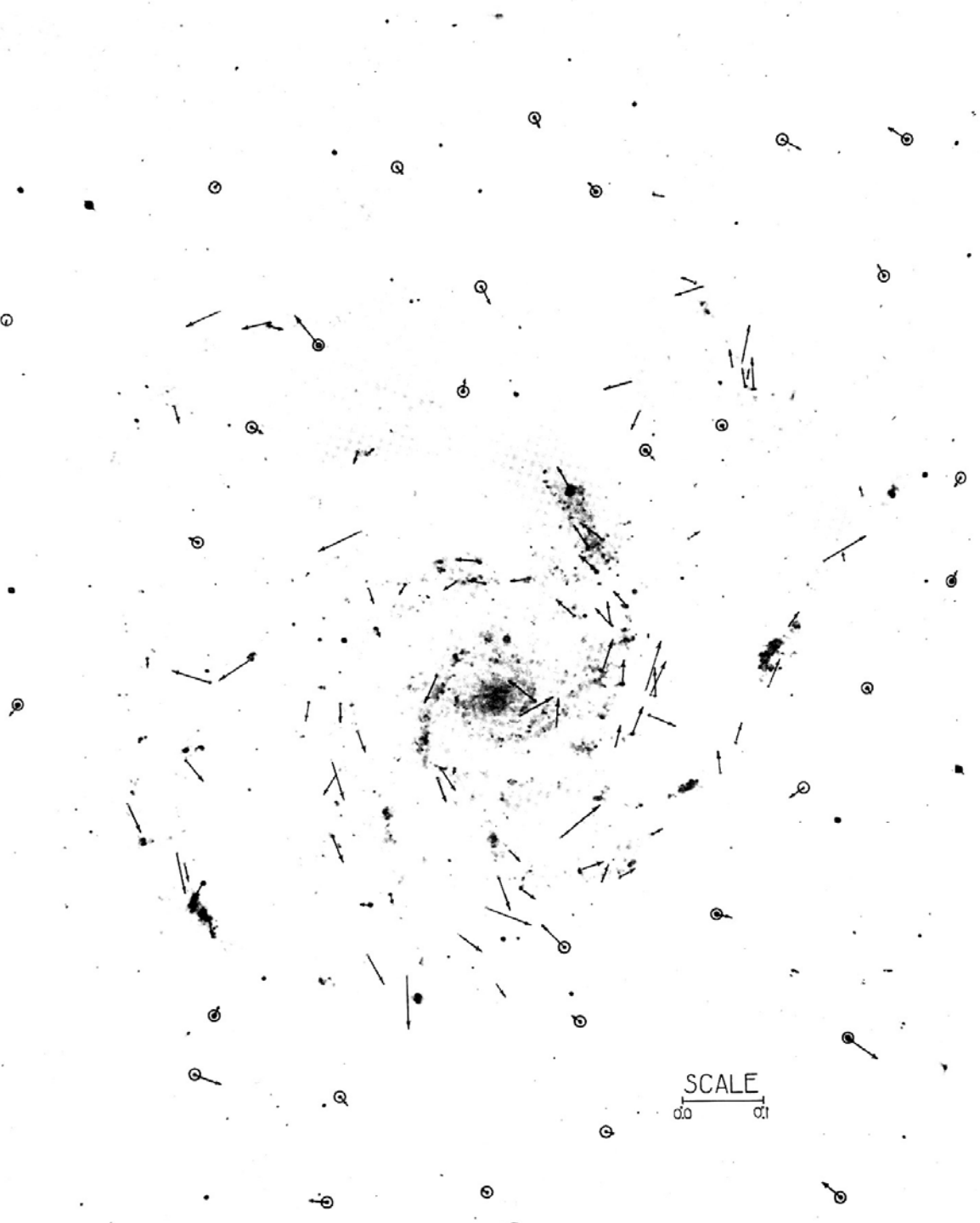
Heber Curtis
1872 - 1942

Harlow Shapley
1885 - 1972

Talking points in the Great Debate

1. Rotation of M101
2. Variable stars
3. Stars or gas
4. Spatial distribution & velocity

M101

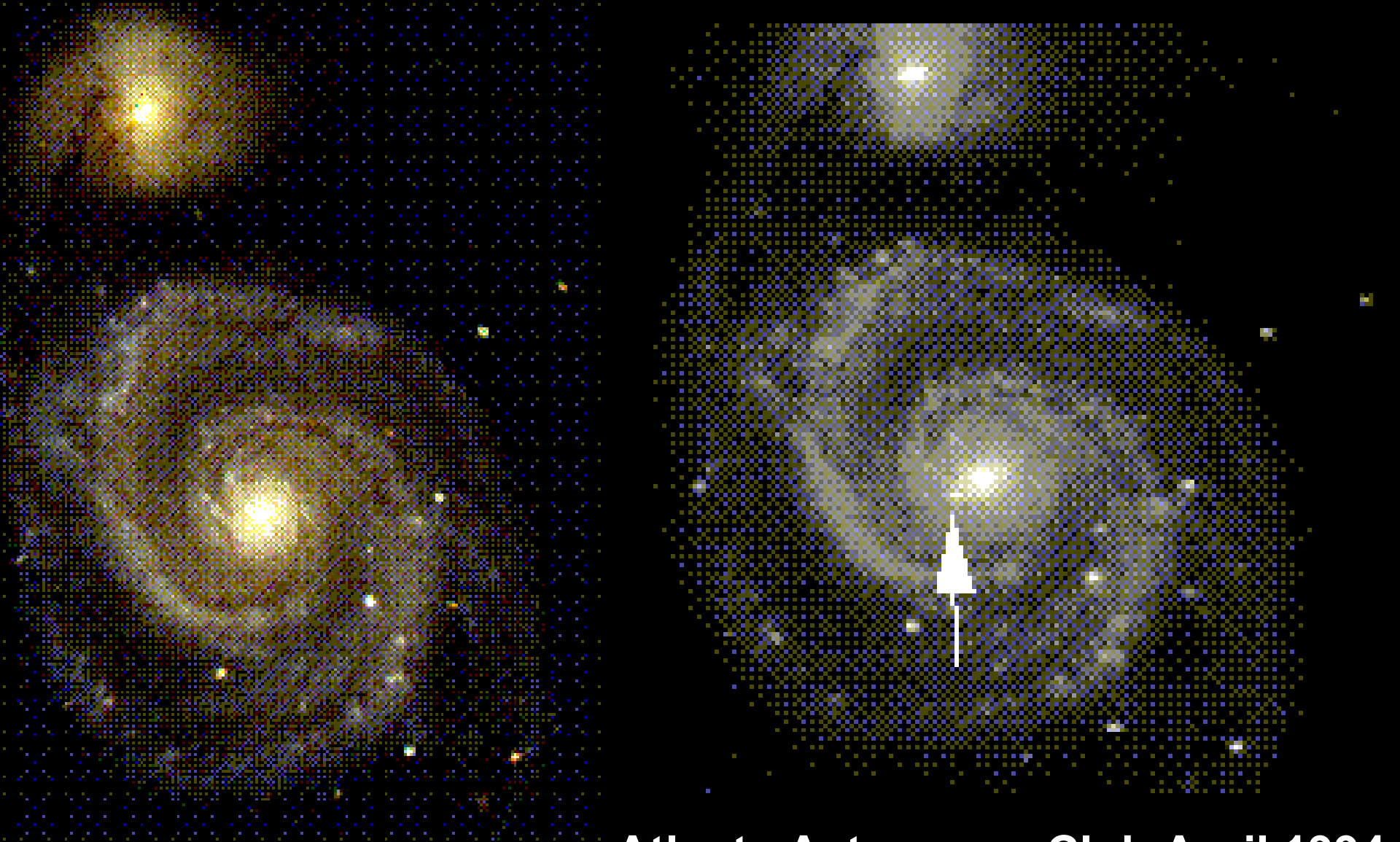


Adriaan van Maanen
1916

M101

Talking points in the Great Debate

1. Rotation of M101
2. Variable stars
3. Stars or gas
4. Spatial distribution & velocity

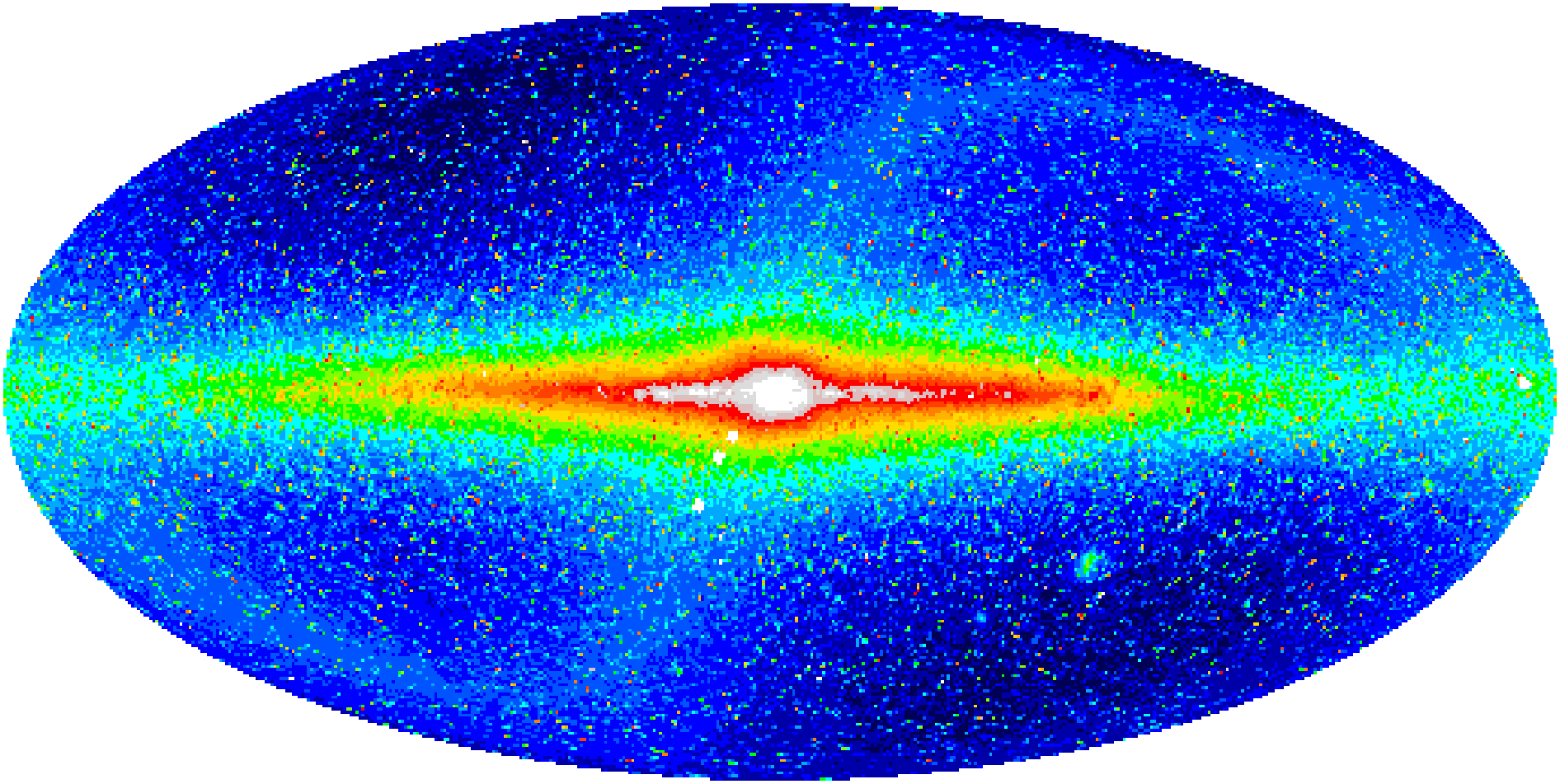


Atlanta Astronomy Club April 1994

Supernova in M51

Talking points in the Great Debate

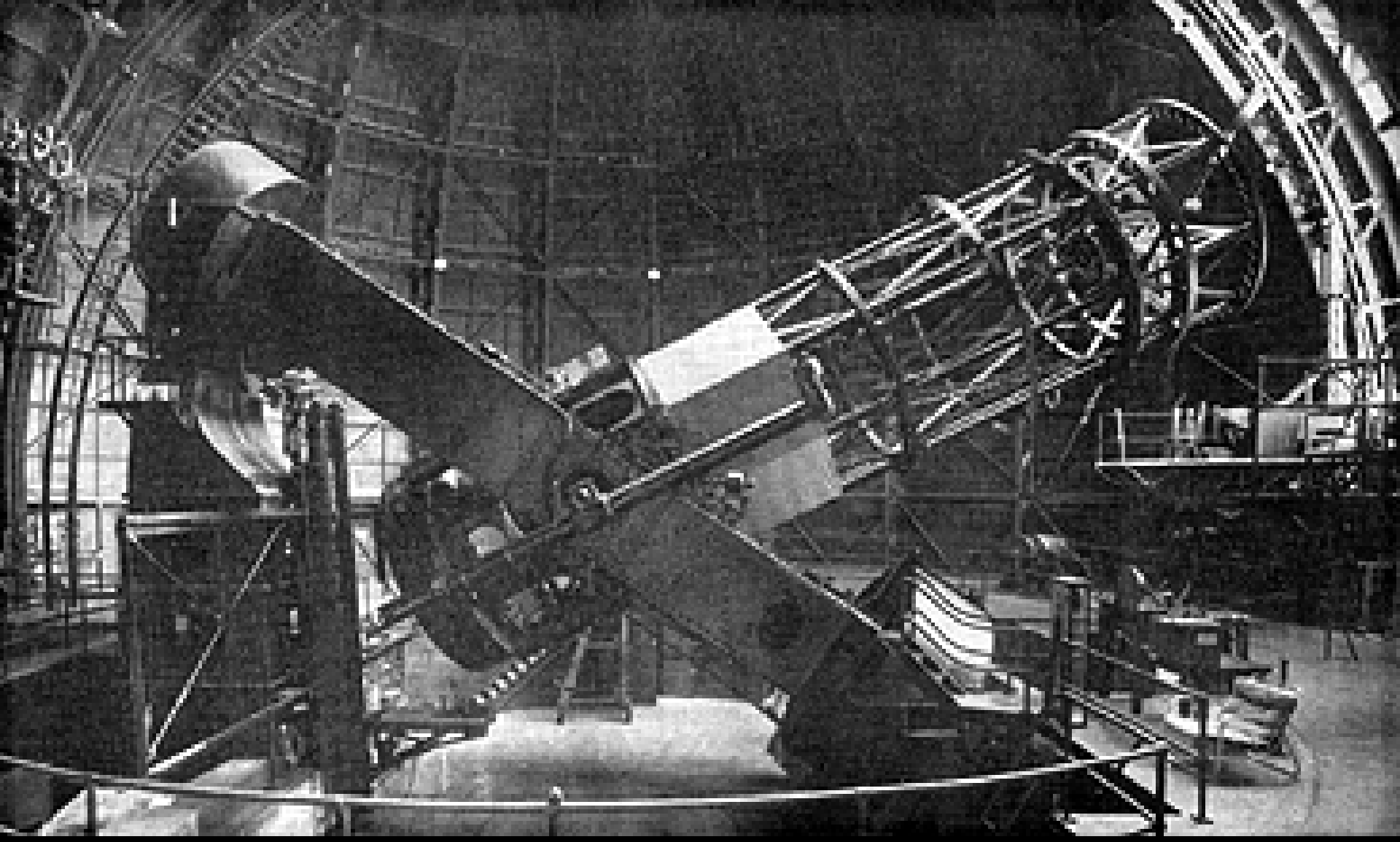
1. Rotation of M101
2. Variable stars
3. Stars or gas
4. Spatial distribution & velocity



Dust in the galactic plane

Edwin Hubble
1884 - 1953

University of Chicago 1909 National Champions

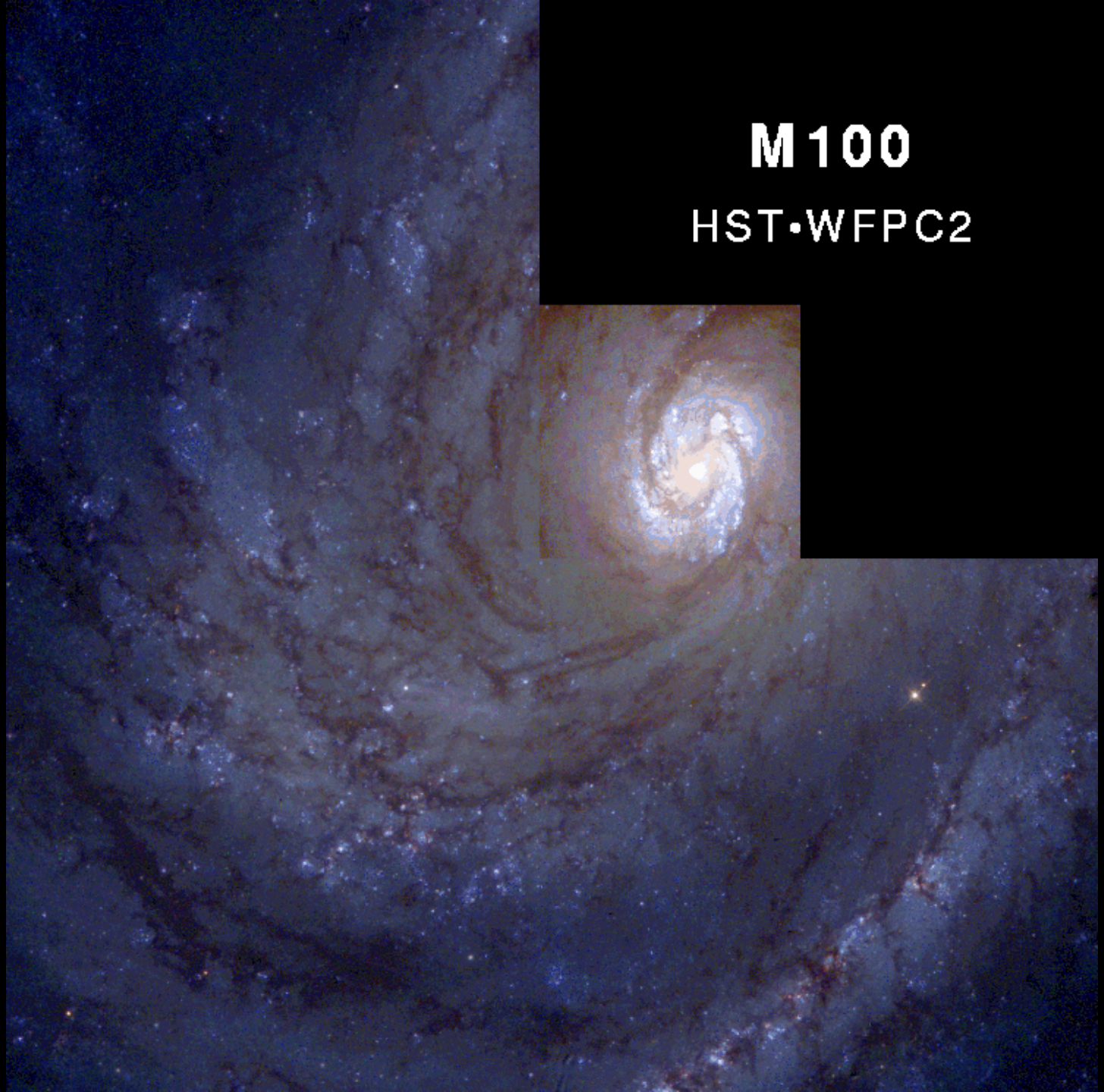


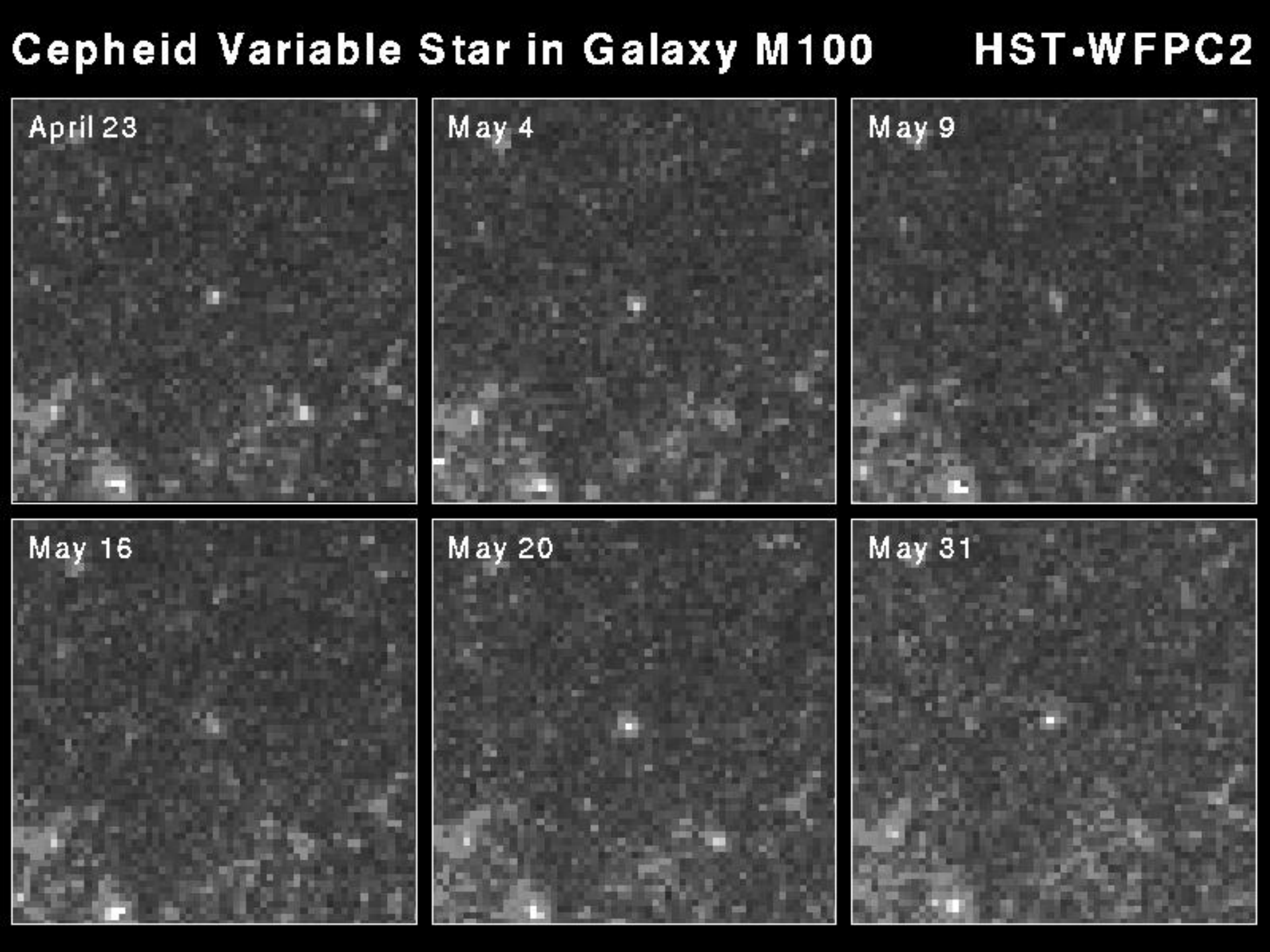
100-inch Hooker Telescope on Mt. Wilson

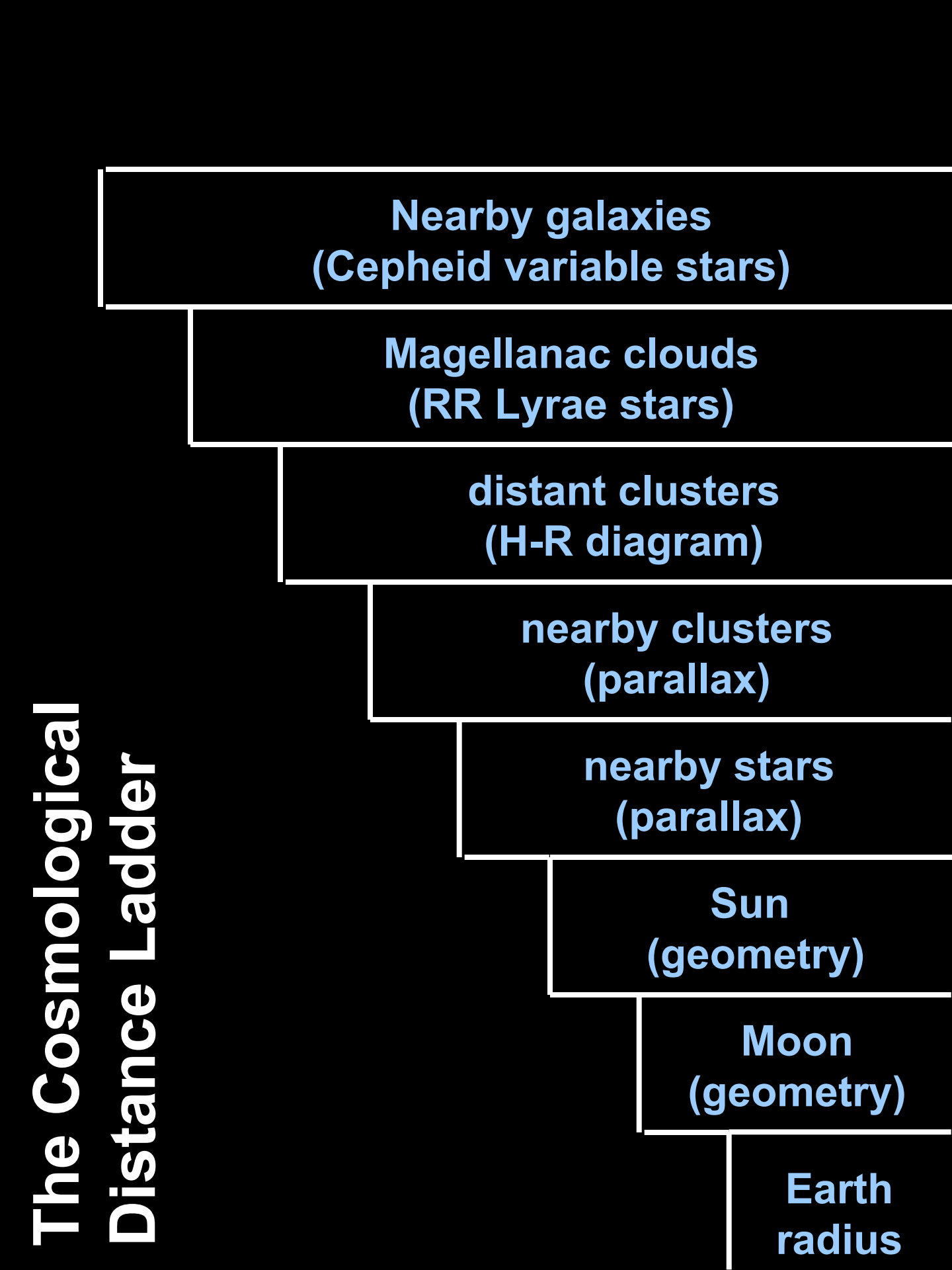
Hubble's Hooker Chair

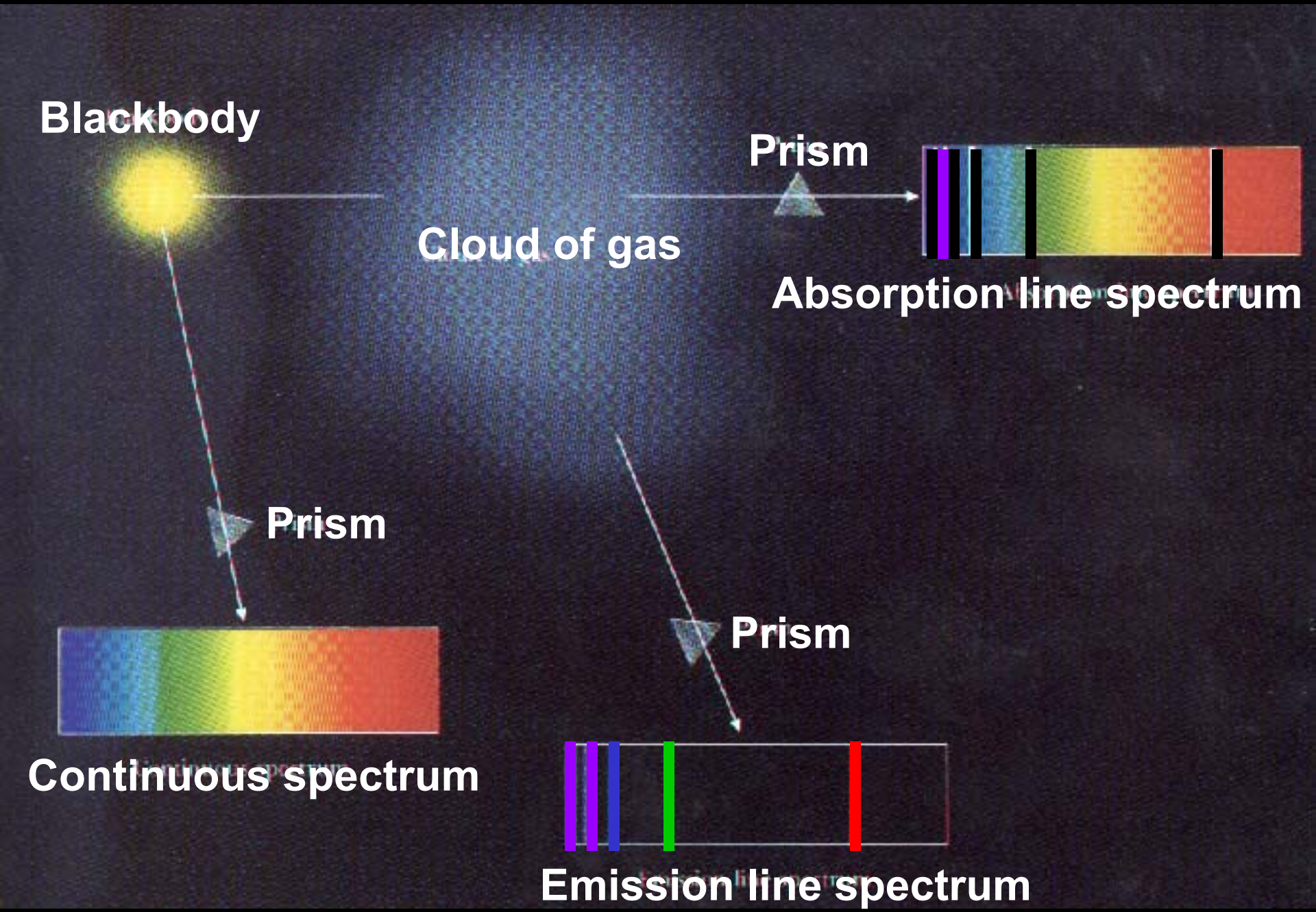

ANDROMEDA
GALAXY


N
VAR!
N
6-Oct
1923
N


M100
HST•WFPC2


Cepheid Variable Star in Galaxy M100
HST•WFPC2
April 23
May 4
May 9
May 16
May 20
May 31


The Cosmological Distance Ladder
Nearby galaxies (Cepheid variable stars)
Magellanac clouds (RR Lyrae stars)
distant clusters (H-R diagram)
nearby clusters (parallax)
nearby stars (parallax)
Sun (geometry)
Moon (geometry)
Earth radius

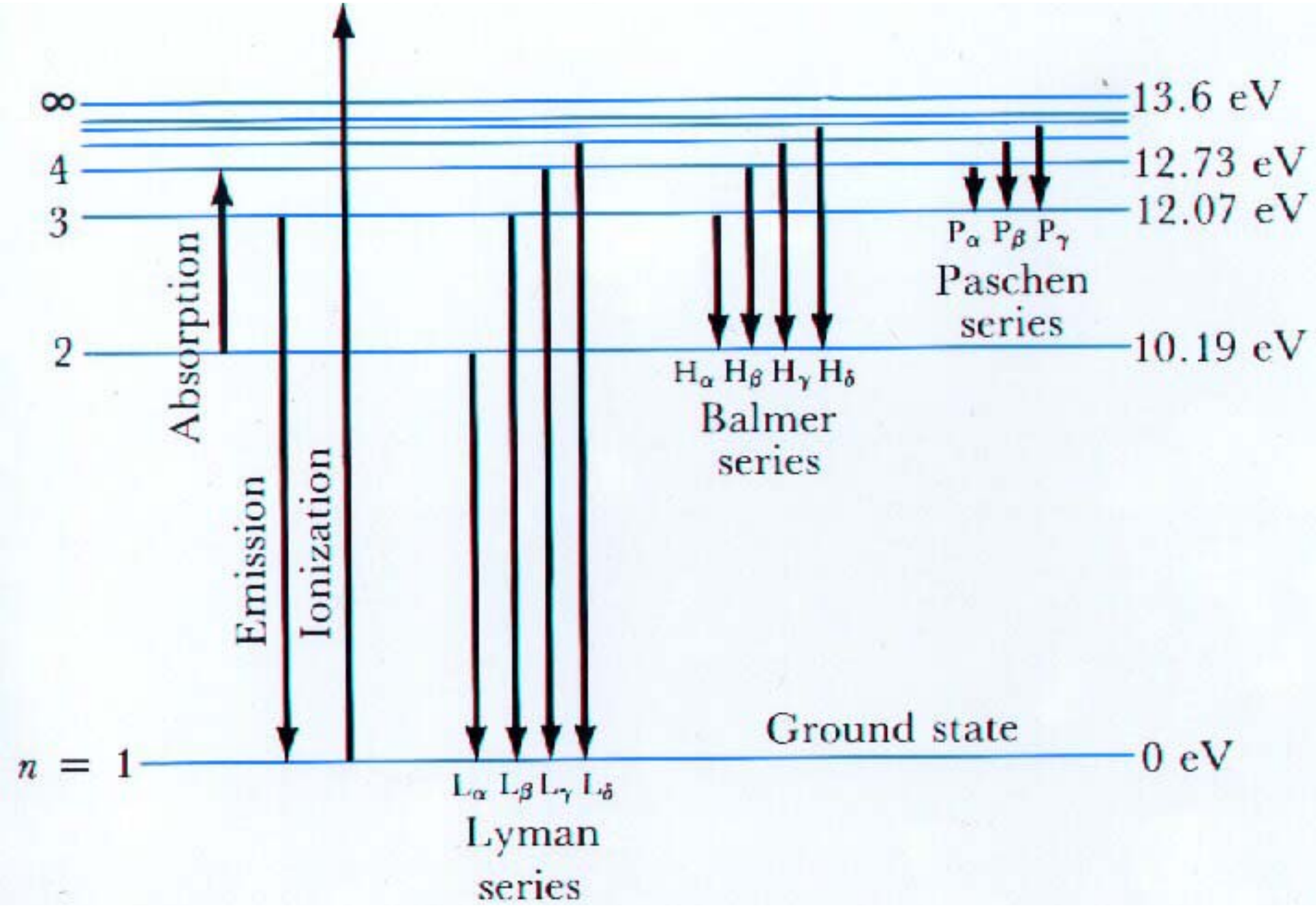

Blackbody
Prism
Cloud of gas
Absorption line spectrum
Prism
Prism
Continuous spectrum
Emission line spectrum

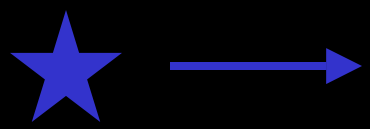
Nothing exists but atoms and empty space; everything else is opinion.

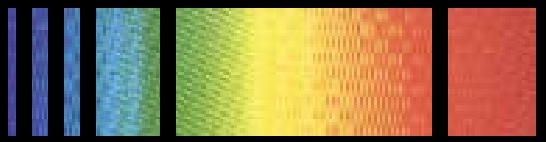
- Demokritos

Everything has been thought of before. The problem is to think of it again.

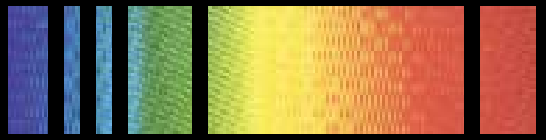
- Goethe

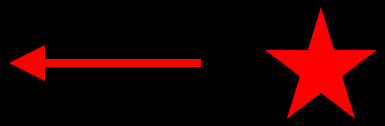

∞
4
3
2
n = 1
13.6 eV
12.73 eV
12.07 eV
10.19 eV
0 eV
Absorption
Emission
Ionization
Pα Pβ Pγ
Paschen series
Hα Hβ Hγ Hδ
Balmer series
Ground state
Lα Lβ Lγ Lδ
Lyman series

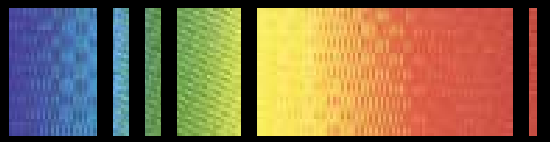




blue shift







red shift

Hubble's Discovery Paper - 1929

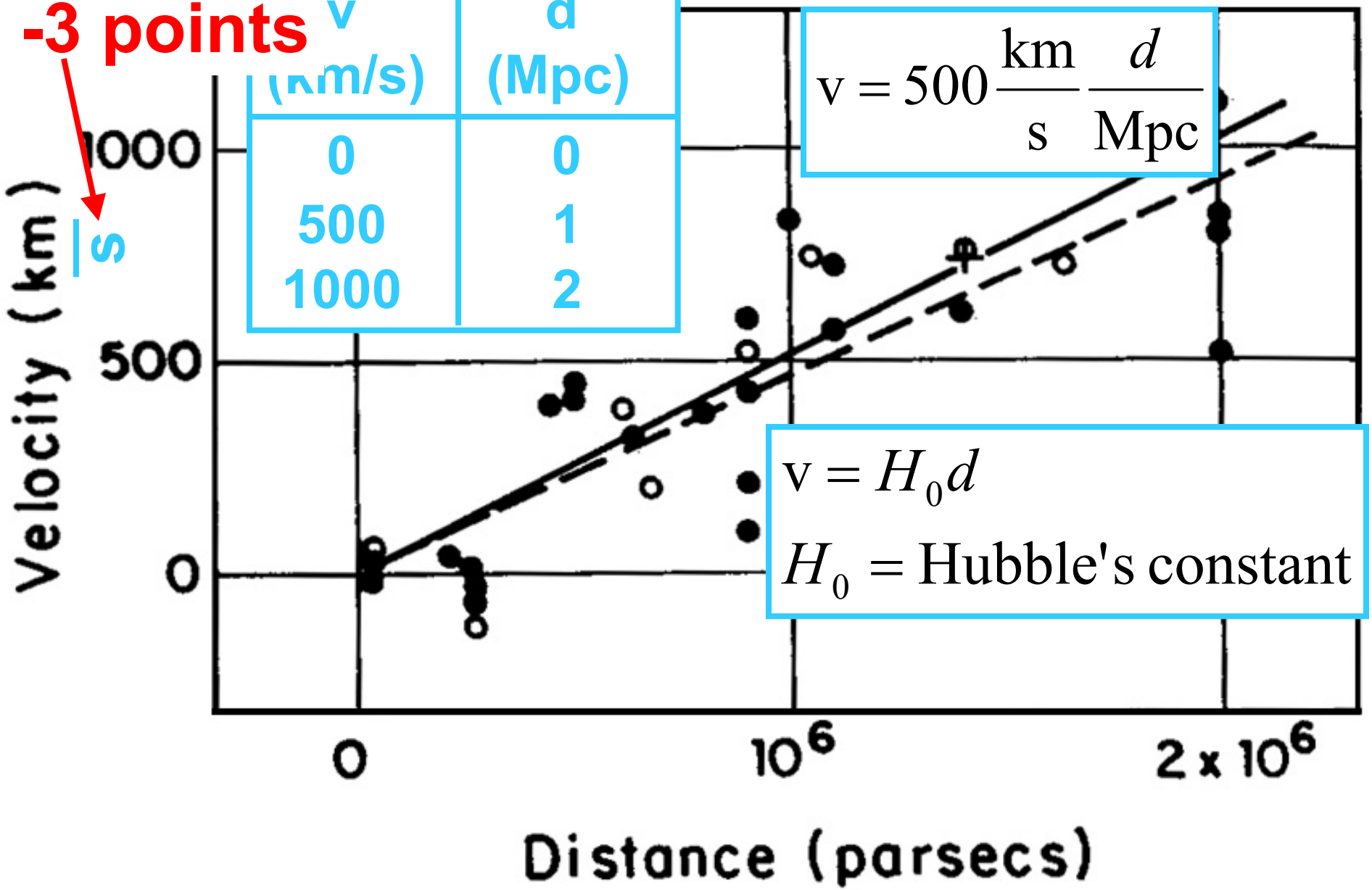
-3 points

v (km/s)	d (Mpc)
0	0
500	1
1000	2

$$v = 500 \frac{\text{km}}{\text{s}} \frac{d}{\text{Mpc}}$$

$$v = H_0 d$$

H_0 = Hubble's constant



$$v = H_0 d$$

H_0 = Hubble's constant

$H_0 = 500\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$	**Hubble**	**1929**
$H_0 = 100\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$		**1960s**
$H_0 = 55\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$		**1970s**
$H_0 = 65\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$		**1990s**
$H_0 = 75\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$		**2001**

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With Real
Cinnamon & Spice
All Natural Flavors

FACT OR FICTION

SCIENCE

The universe is shrinking and will soon be the size of a golf ball.

See other side for answer.

CONVENTIONAL DIRECTIONS

Empty packet into bowl.
Add **1/2 cup** boiling water; stir.

MICROWAVE DIRECTIONS

Empty packet into microwaveable bowl.
Add **2/3 cup** water or milk.
Microwave at **HIGH** about 1-2 minutes; stir.
Use care when removing cereal from microwave; bowl may be hot.

For **thicker** oatmeal decrease liquid; for **thinner** oatmeal increase liquid.

THE ANSWER

Fiction! Most stars and galaxies are moving away from the earth which means the universe is actually getting bigger.

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FACT OR FICTION

SCIENCE

Sir Isaac Newton discovered gravity by watching an apple fall.

See other side for answer.

CONVENTIONAL DIRECTIONS

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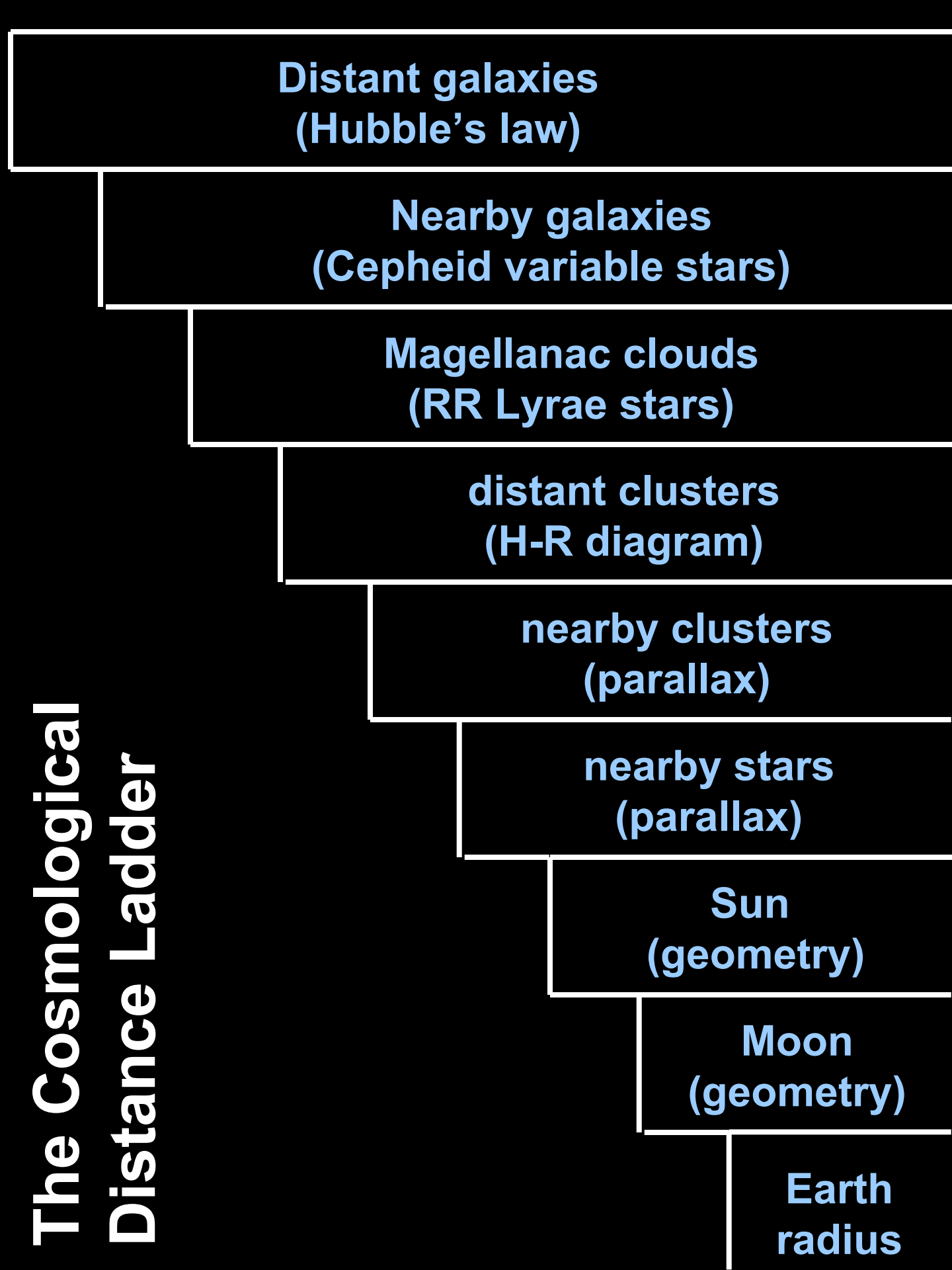
THE ANSWER

Fact! Newton made his famous discovery as a young man but was unable to prove it until almost 20 years later.


Distant galaxies
(Hubble's law)
Nearby galaxies
(Cepheid variable stars)
Magellanac clouds
(RR Lyrae stars)
distant clusters
(H-R diagram)
nearby clusters
(parallax)
nearby stars
(parallax)
Sun
(geometry)
Moon
(geometry)
Earth
radius
The Cosmological
Distance Ladder

$$v = H_0 d$$

H_0 = Hubble's constant

Let's assume $H_0 = 100\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$

$$v = 100 \frac{\mathrm{km}}{\mathrm{s}} \frac{d}{\mathrm{Mpc}}$$

v	d
$100\ \mathrm{km\ s^{-1}}$	$1\ \mathrm{Mpc}$
$1{,}000\ \mathrm{km\ s^{-1}}$	$10\ \mathrm{Mpc}$
$10{,}000\ \mathrm{km\ s^{-1}}$	$100\ \mathrm{Mpc}$
$100{,}000\ \mathrm{km\ s^{-1}}$	$1{,}000\ \mathrm{Mpc}$

We are not the center of the expansion of the universe

Every galaxy sees the expansion

Cosmological Principle

The universe is the same everywhere

- no special point in the universe (no center)
- no special set of points (no edge)

In the field of modern cosmology, the first principle is called the “Cosmological Principle. It states that the universe has no center, that it has the same properties throughout. Every place in the universe has, in this sense, equal rights. How can the human race, which has evolved in a universe of such fundamental equality, fail to strive for a society without violence and terror? How can we fail to build a world in which the rights of every human from birth are respected?

Fang Li Zhi
Acceptance speech
for the
Robert F. Kennedy
Memorial Human
Rights Award